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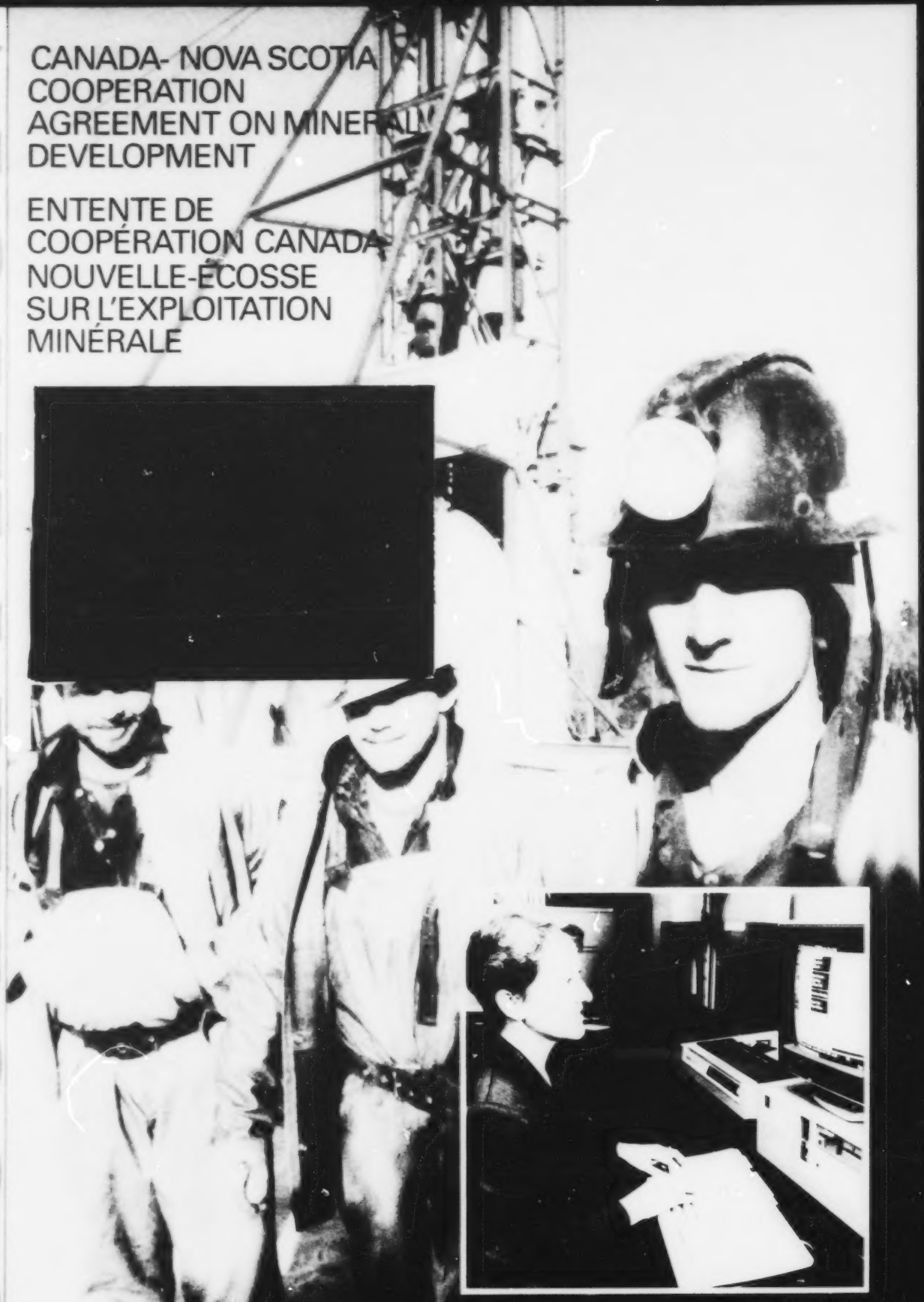

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VOL VI of VII

A STUDY ON THE CONTROL OF GROUNDWATER HAZARD AT GAYS RIVER MINE

VOLUME VI

OFFICE AIRPHOTO MAPPING AND CORRELATION OF SINKHOLES WITH AVAILABLE MAPS AND REPORTS: GEOLOGIC AND HYDROGEOLOGIC DATA SYNTHESIS - WESTMINER MINE SITE AND SURROUNDING AREA

by: J.D. Mollard & Associates Ltd.

70 pp + figs

MICROMEDIA

J D MOLLARD AND ASSOCIATES LIMITED

CONSULTING CIVIL ENGINEERS AND ENGINEERING GEOLOGISTS

OFFICE AIRPHOTO MAPPING
AND CORRELATION OF SINKHOLES
WITH AVAILABLE MAPS AND REPORTS:
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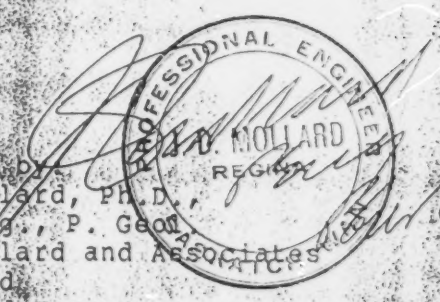

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Attention: Mr. Tom Lamb
July 12, 1991

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OFFICE AIRPHOTO MAPPING AND CORRELATION OF SINKHOLES WITH AVAILABLE MAPS AND REPORTS GEOLOGIC AND HYDROGEOLOGIC DATA SYNTHESIS WESTMINER MINE SITE AND SURROUNDING AREA

1 TERMS OF REFERENCE

The initial request for this study came from Mr. Wayne Clifton, P. Eng., Clifton and Associates, Regina, who supplied three lines of 1:10,000 colour airphotos of the Westminer Canada mine site area. Terms of reference called for obtaining additional B&W airphotos as well as bedrock geology, surficial geology and hydrogeology maps and reports of the study area; mapping sinkholes over a signficant area around the mine; then synthesizing and correlating the map and airphoto data.

A subsequent long-distance phone call discussion with Mr. Tom Lamb of Westminer Canada confirmed the study. Mr. Lamb also forwarded a number of maps and reports, to be studied with map information and additional airphotos collected from other sources.

Terms of reference therefore entail preparation of a synthesis report covering all accumulated information and supported by figures, conclusions, and recommendations related to the ongoing mine-inflow and mine flooding problems at Westminer Canada.

2 THE GROUNDWATER MINE-INFLOW PROBLEM

Mining problems caused by groundwater inflows have been a concern at Gays River mine (now Westminer Canada mine) since the mine was opened in 1979 (McKee and Hannon, 1982; Meyer, 1991). Mine development has been intermittently disrupted and the heading flooded, necessitating pumping (dewatering) and mucking out. Over the years several mine dewatering techniques have been used.

Mining problems have been complicated by groundwater originating in several bedrock and overburden aquifers, the precise locations and extent of which are difficult to pinpoint in advance of trouble.

Simple solutions to Westminer's groundwater problems are complicated by the complex nature of the geometry and geology, including multiple bedrock and overburden aquifer systems.

Potential bedrock sources of water that may be involved to greater or lesser degrees include water-bearing fractures and fissures in Meguma Group quartzites, especially in tectonically deformed strata and near lithologic contacts; solution-enlarged joints, faults and cavities in the ore-bearing carbonate rock; sinkholes and solution-enlarged piping passageways in Windsor Group evaporites adjoining and near the ore body; and randomly occurring permeable bodies in Cretaceous sediments that infill a karst valley between Windsor evaporites and Gays River Formation carbonates.

Overburden aquifers can be just as complicated as bedrock aquifers in terms of their location, geometry and geology. Difficult-to-predict locations of water-bearing sand and gravel bodies may occur as isolated pockets, layers and lenses in subtill, intratill, and intertill depositional environments in the Westminer Canada mine area. In places they are overlain by thick permeable glaciofluvial deposits (valley outwash and glacial-delta sediments) below roughly elevation 100 ft (30.5 m) in the study area.

In the Gays River valley, glaciofluvial sediments of varying permeability are overlain by postglacial floodplain alluvium, whose grain-size composition can vary from coarse (sandy) to fine (clayey), depending on location.

Permeable contact zones between diverse rock types, as well as between different rock types, and permeable overburden deposits further complicate the hydrogeological picture. They point to a very complex groundwater problem, and the need for the broadest possible perspective in trying to identify various sources of groundwater, their location and extent, their permeability characteristics, and where they are most likely to occur in plan and profile in the Westminer Canada mine area.

Owing to the complicated nature of the water inflow problem from previous knowledge of the geology and hydrogeology, I decided that existing relevant bedrock and surficial geology map and report data should be collected from various sources and then synthesized. Others might then evaluate the synthesized information in light of

karstic solution features appearing on several sets of black-and-white and one set of colour airphotos.

3 DATA SOURCES -- PARTIAL LIST

Following is a partial list of maps and reports forwarded by individuals possessing knowledge of the geology, hydrogeology, and past groundwater problems at Westminer Canada:

- The Hydrogeological Environment at Gays River Mine, Gays River, Nova Scotia, by D.M. McKee and P.L. Hannon, May, 198, 21 p., 9 figures, 23 references.
- Phase 1 Hydrogeologic Investigation Gays River Mine, by Leggette, Brashears & Graham, Inc., April, 1982, 27 p., 5 figures, appendix.
- Gays River Bathymetric Survey, by Martec Limited, June, 1990, 3 p., 2 figures, appendix, 11 ore reserve plan sheets.
- Gays River Mine Dewatering and Water Inflow Prevention, by G.M. Meyer, Western Mining Corporation Ltd., Australia, February, 1991, 18 p., 7 tables, 15 figures, 1 plan, 3 appendicies.
- Pleistocine Geology, Central and Eastern Shore Regions, Sheets 1, 2, 3 and 4, scale 1:100,000, 1979 and 1980, Nova Scotia Department of Mines, by R.R. Stea and J.H. Fowler, 4 sheets.
- Shubenacadie Geology Map 1067A by I. M. Stevenson, GSC, 1959, 1 map.

- Surficial Geology of the Shubenacadie Map Area, Nova Scotia (Report and Map 6-1956), by Owen L. Hughes, 10 p., 1 map.
- Groundwater Probability Map 1160A, Truro, West Half, by L.V. Brandon, 1966, 1 map.
- Geological Map, Westmine Mine Site, scale 1:10,000, February, 1991.
- Early Cretaceous Deposits in the Gays River Lead-Zinc Mine, Nova Scotia, by E.H. Davies, S.O. Akande, and Marcus Zentilli, Part A, GSC Paper 84-1A, 1984, p. 353-358.
- Thermochronologic Constraints on Ore Formation at the Gays River Pb-Zn deposit, Nova Scotia, by D.C. Arne, I.R. Duddy and D.F. Sangster, Can. J. Earth Sciences, v. 27, no. 8, August, 1990, p. 1013-1022.
- Shubenacadie NTS map sheet 11 E/3, 1982, scale 1:50,000, contour interval 50 ft, by Energy, Mines and Resources, Ottawa, 1 map.
- Geological Map 82-4 of the Shubenacadie and Musquodoboit Basins, Central Nova Scotia, by P.S. Giles and R.C. Boehner, Nova Scotia Department of Mines and Energy, scale 1:50,000, 1982, 1 map.
- Carbonate Buildups of the Gays River Formation, Lower Carboniferous Windsor Group, Nova Scotia, by R.C. Boehner, P.S. Giles, D.A. Murray and R.J. Ryan, Can. Soc. Petrol. Geol. Memoir 13, 1989, p. 609-621.
- Stratigraphy and Depositional History of Marine Evaporites in the Windsor Group, Nova Scotia, Shubenacadie and Musquodoboit Structural Basins, Nova

Scotia, Canada, by R. C. Boehner, Nova Scotia Department of Mines and Energy, 1X-1CC v. 3, p. 163-178.

- Lithostratigraphic, Geological and Paleogeographical Setting of Carbonate Buildups in the Lower Carboniferous Windsor and Horton Groups, Nova Scotia, by R.C. Boehner, Nova Scotia Department of Mines and Energy, NSDME Report 88-1, p. 143-151.
- Depositional Environment of the Gays River Reef, Nova Scotia, Canada, by P.E. Schenk and B.L. Hatt, 1984, in Ninth International Congress on Carboniferous Stratigraphy and Geology, Urbana, Illinois, Compte Rendu, v. 3, p. 117-130.

4 APPROACH TO SINKHOLE MAPPING AND GEOLOGIC DATA SYNTHESIS

Because the geometry and permeability of bedrock and surficial geology aquifers largely determine the Westminer mine inflow problems, and because the bedrock surface is masked by several different kinds of overburden deposits, I thought I should obtain as much existing map and report data as practical. The culled pertinent information would then be correlated and interpreted along with airphoto-identifiable sinkholes. This was done, resulting in 37 figures.

Emphasis was placed on the kinds of geological and hydrogeological plan and cross-sectional information that might be useful in correlating with sinkholes. Identified sinkholes in the landscape are all very young, geologically

speaking -- less than 13,000 years old. Many are forming or actively enlarging at the present time.

Windsor Group evaporite strata are over 300 million years old, whereas the present-day land surface, widely pockmarked with sinkholes, is less than 13,000 years old. Accordingly, a very long geologic time interval was available for karstic solution features to develop before the advance and retreat of the last ice sheet to cover Westminer Canada mine. In short, over 300 million years were available to develop higher concentrations of sinkholes than have formed in the last 13,000 years. On the other hand, multiple (perhaps four) glaciations may have stripped away much of the solution-affected preglacial land surface on exposed Windsor evaporite terrain.

Part of the objective here then is to try to understand the surficial and bedrock geology so far as possible: the effects of lithologic contrasts, structural activity along ancient fracture trends, and their influence on preglacial bedrock topography and on the distribution of different types and permeabilities of glacial deposits. They provide the background to evaluating mine-inflow problems and their possible remedy.

5 BEDROCK GEOLOGY AND HYDROGEOLOGY

The Westminer Canada mine site -- formerly called the Gays River mine and the Gays River Pb-Zn deposit -- is located on a paleotopographic high separating the Shubenacadie and Musquodoboit basins (Figure 1). The Gays

River Bank is one of 28 carbonate mounds, called banks, in the Gays River Formation (number 25, Figure 2).

The Gays River Bank overlies a long sinuous ridge of Cambro-Ordovician Meguma Group quartzite. The ore-bearing reef carbonate bank was later buried beneath Carboniferous Windsor Group evaporites, consisting of gypsum and anhydrite in the Westminer mine area (Figures 3 and 4).

Stratigraphic units in the Westminer area are written out in Figure 4. This figure is followed by a diagram in which each formation or group is represented by letter symbols (Figure 5). Age and lithology of the different formations and groups in the mine area are explained in the map legend prepared by Giles and Boehner in 1982 (Figure 6). Letter symbols for various rock units and their descriptions can be correlated with locations of the different formations and groups underlying the cover of glacial sediments (Figure 7). Figure 7 shows formation and group ages, lithologic contacts and contrasts, as well as regional structures such as folds and faults. Two synclines, for example, can be seen flanking an anticlinal ridge in Cambro-Ordovician Meguma Group quartzite. (This rock type is also referred to as quartz metawacke and greywacke on different maps).

Two main tectonic events that followed deposition of Windsor Group evaporites took place around 290 and 210 million years ago (column 3, Figure 8). These deep-seated structural disturbances likely resulted in creation of fault and joint fractures, increasing rock fracture porosity and permeability in the mine area. In addition, rock

permeability was enhanced along steep contacts between quartzite and carbonate strata. A thin zone between quartzite and carbonate is characterized by a coarse talus breccia deposit (Figure 9A). Schenk and Hatt (1984) give a good description of the depositional environment of the Gays River reef carbonate (Figure 9B).

The high-grade lead-zinc orebody is controlled by reef morphology and porosity as well as by faults cutting both Meguma Group quartz metawacke and Gays River Formation reef dolomite, the latter also referred to as dolostone (Figure 10 and 11). Figure 10 also shows what is probably an infilled karst valley, formed between Windsor Group evaporites and Gays River Formation reef dolomite. This inferred karst valley, called "the Trench," is filled largely with a complex assortment of clays and silts (muds), coal, blocks of evaporite, and sand and gravel (quartz pebbles) pockets of Cretaceous age (135 to 65 million years ago) as well as by deposits of Pleistocene age (less than 2 million years old). The precise time over which this trench was formed and filled is difficult to say. It may have undergone several episodes of erosion, both solution and fluvial, and deposition.

In plan view the trench system, known to contain pockets of permeable water-bearing sediment, follows the northwest side of the reef-covered Meguma anticlinal ridge and in several places cuts the lead-zinc orebody (Figure 12).

A postulated sequence of geologic events (age, structural relationships, lithology, and hydrogeological

characteristics) is portrayed in a diagram showing stratigraphic units, prepared by McKee and Hannon in 1982 (Figure 13). The authors also developed cross-sectional sketches and block diagrams (schematics not to scale) to illustrate the vertical arrangement of hydrogeological events at what was then called the Gays River mine (Figures 14 to 17). These sketches reveal the envisaged complexity of pervious water-bearing material causing mine-inflow problems. Trench sediment grain-size distribution curves (Figure 18) indicate the material to be a dirty sand and fine gravel that can contain a high amount of fines (silt plus clay).

In correlating map and airphoto-identified sinkhole locations with likely sources of groundwater within the bedrock, based on the data summary outlined above, the following should be kept in mind.

- A thin, and perhaps discontinuous, cover of coarse angular talus occurs over the steep northwest side of a Meguma Group quartzite ridge.
- Fractures, mainly systematic jointing, in Meguma Group quartzite are more likely open and able to carry water near the old erosional surface -- e.g., near its contact with Gays River Formation dolostone.
- Rejuvenated tectonic deformation events are likely to perpetuate regional systematic joint sets within Meguma Group rocks into overlying sedimentary rock strata -- i.e., tectonic heredity of fracture systems is anticipated.
- Paleokarst solution channels and other geometric forms

of karstic porosity and permeability probably developed in Gays River Formation reef carbonate prior to their buried beneath Windsor Group evaporites.

- Accelerated solution activity appears to have occurred along the contact between Windsor Group evaporites and underlying reef carbonate, creating a winding karst valley following noses and re-entrants on the north side of the locally very steep (70° or so) quartzite ridge.
- In Cretaceous time the winding karst valley, or trench, was infilled with a variety of sediments, including muds, coal, blocks of gypsum and anhydrite, and sand and gravel. Water-bearing pervious pockets (aquifers) in this assemblage of trench material are an additional source of mine-inflow water.

The practical problem facing a mine manager or mine hydrogeologist is that locations of permeable water-bearing fractures, solution and piping features, and sand or gravel pockets are likely randomly distributed and therefore difficult to predict in location in the absence of extensive, and probably expensive, geophysical survey exploration and correlated exploratory testhole drilling.

6 OVERBURDEN GEOLOGY AND HYDROGEOLOGY

Several generalized maps of surficial geological deposits in the area have been prepared. The first surficial geology map I was able to locate was prepared in 1957 by Dr. Owen L. Hughes, Geological Survey of Canada

(Figure 19). Significant findings coming out of Hughes' report are that apparently all small glacial lakes in the study-area reached much the same upper water elevation, about 105 ft (32 m), and that abundant nearshore deltaic sands and gravelly sands and lesser deposits of offshore deep-water silt and clay were deposited in Westminer Canada mine area. Moreover, in the Gays River valley east of the Westminer Canada mine, one can identify ice-contact kames, an esker, and a proglacial sand and gravel outwash-delta that has been cut through and terraced by postglacial meltwaters and by modern stream erosion. Thus the Gays River valley and adjoining lowlands below about 105 ft (32 m) in the mine area (Figures 20 and 21) are likely underlain by thick fluviodeltaic sands and silty sands along with interbedded thin impervious silt and clay layers and lenses. Land above the 105 ft (32 m) contour in Figure 20 appears cross-hatched in Figure 21. Areas below 105 ft (32 m) elevation are expected to harbour surficial interbedded sands, silts and clays of glaciofluvial and glaciolacustrine origin. These stratified waterlaid sediments are not shown on the 1979 regional Pleistocene geology map prepared by Stea and Fowler (Figure 22). However, the esker-kame-outwash delta deposit at Cooks Brook is shown (dark area, Figure 22). Elevation of that delta surface is around 100 ft (30.5 m) and matches, approximately, the surface elevation of the gravel deposit, with an open pit in it, across the river from Gays River hamlet.

The original valley outwash fill was stream-eroded to some undetermined (and perhaps considerable) depth before

the modern surficial floodplain alluvium was deposited. Thus the depth, stratigraphy, and composition of stratified permeable deposits below the Gays River floodplain is not known -- or at least to this writer.

The distribution of till and glaciofluvial deposits and floodplain alluvium are shown in a map accompanying Meyer's report (Figure 23). I believe Figure 23 is based on a graduate thesis mapping project by S.O. Akande, under the direction of Professor Marcus Zentilli at Dalhousie University. Incidentally, the contour map in Figure 23 has a different elevation datum than the 1:50,000 NTS mapsheet IIE/3. On Figure 23 the upper limit of pervious glaciofluvial deposits is controlled by glacial lake and meltwater streambed levels, which are horizontal or gently sloping. Therefore, theoretically, sand and gravel should not lap up irregularly on to the sides of drumlins (Figure 23).

Leggette, Brashears and Graham, Inc., show the locations of sinkholes on the upland, away from the river channel and valley, sinkholes below the Gays River bed, and streamlined and hummocky hill terrain in other locations (Figure 24).

Based on the locations of underground mine workings, contacts of different bedrock formations and groups, the trench, surface geologic deposits, and the location of sinkholes reported by others, a composite map was prepared in an attempt to synthesize available geologic map data (Figure 25). This map shows geological and hydrogeological

data in preceeding figures at the same scale, and on a single plan. Data appearing on Figure 25 suggest that many sinkholes follow the Gays River valley, possibly an ancestral solution valley. The Westminer mine area therefore coincides with a location where there is a high incidence of surficial aquifers and relatively little till.

Smaller sand or gravel aquifers, possibly occurring as pockets in the trench, follow a preglacial karst valley. A number of observation wells (OW), dewatering wells (DW) and exploratory test wells (ETW) follow the general trend of the trench's surface projection (Figure 26). Construction details of an underground dewatering well that taps into the trench is shown at the bottom of Figure 26. Design of such wells is important so as not to plug off and become inoperative.

7 AIRPHOTO-IDENTIFIED SINKHOLES

Sinkholes observed in the field are shown on geological maps prepared by O. L. Hughes in 1957 and by I.M. Stevenson in 1959 (Figure 19). These field-observed sinkholes, as well as additional ones, have been identified on several ages, scales, and types of airphotos (both B&W and colour). In this report, sinkholes are shown on photocopied airphotos (Figures 27 to 34).

The sinkholes are outlined on different ages of photography and on different types of airphotos (B&W and

colour) as follows:

Figure number	Year of photography	Type of airphoto
27	1979	B&W
28	1954	B&W
29	1954	B&W
30	1954	B&W
31	1990	Colour
32	1990	Colour
33	1959	B&W
34	1990	Colour

Figure 27 (1979)

The sinkholes identified on Figure 27 tend to be concentrated more heavily along trends of lithologic contacts and structurally controlled depressions. Many sinkholes appearing in Figure 27 are prominent, and are larger than those whose locations appear on Figure 29.

Figure 28 (1954)

Three sinkholes appear north of the large waste disposal pond, located south of the Westminer site. Whether or not these sinkholes affect mine inflows when water levels in the waste disposal pond are high is not known. Three large sinkhole locations also appear southeast of the waste disposal pond, the largest sink being the centre one. The westerly sinkhole location consists of three smaller individual sinks, outlined again on Figure 33. In the Figure 28 airphoto, taken in 1954, less obvious and

therefore inferred sinkholes occur along the Gays River floodplain, east of the mine portal.

It is worth noting that the age of those sinkholes located above the surfaces of alluvial floodplains is less than 13,000 years old (postglacial in age), and that the development of smaller sinkholes along the Gays River floodplain will be modified and perhaps obscured by ongoing alluvial sediment buildup and channel shifting.

Figure 29 (1954)

Nearly all sinkholes outlined on Figure 29 are located along larger river valleys and small channelways, where surface runoff and run-in (infiltration) are enhanced. However, sinkholes on Figure 29 are small and weakly expressed in the relief.

Figure 30 (1959)

Locations of sinkholes appearing on Figure 30 suggest a number of correlations -- namely, that the roughly 100 sinkholes shown tend to be preferentially concentrated in the following physical environmental settings:

- along river valleys (floodplains and valley walls).
- along linear depressions that mark the contact between nonsoluble rocks (Meguma Group quartzite) and soluble rocks (Gays River Formation carbonates and Windsor Group evaporites).
- along ancestral (preglacial) karst valleys.

- in and particularly around the margins of late glacial glaciofluvial sand and gravel deposits.

In addition, in many locations sinkholes tend to be clustered in groups. Note also the two gravel pit locations. At one time the two granular deposits may have been connected since both are around 32m in elevation.

Figure 31 (1990)

Figure 31 is an interesting airphoto in that the preponderance of sinkholes are located along the Gays River floodplain. The smaller sinkholes look very shallow. I have referred to them as "inferred" sinkholes because there are so many of them, and they occur along floodplain reaches subject to flooding, thus being modified in appearance.

Figure 32 (1990)

The area around the mine having the largest concentration of large and active looking sinkholes appears in Figure 32. Here the sinkholes are located along and near a V-shaped linear depression believed to be an ancestral karst valley.

Figure 33 (1954)

This figure, once again, shows the tendency for sinkholes to cluster along depressions, which are likely either lithologically or structurally controlled. They are also places where hydraulic heads are increased during times of heavy rainfall and snowmelt, and therefore flooding.

Gravel pits in terraces west of Cooks Brook and just upstream of the confluence of Gays River and the South Branch of Gays River suggest that the Gays River valley may have been aggraded with sand and gravel at one time and later eroded by glacial meltwater or postglacial stream action.

Figure 34 (1990)

Figure 34 shows the location of Westminer underground mine workings (in black) in relation to sinkholes from field-observed sources along with additional ones interpreted from airphotos.

Of significance are the large number of sinkholes located below the channel of Gays River (Figure 35).

In Figure 34 a number of small and subtly expressed inferred sinkholes can be seen along the Gays River floodplain, south of the road leading to the mine administration building. They suggest that solution collapse processes are active at the present time.

Figure 35

This figure shows that in one sinkhole the water in Gays River channel is about a metre deep. The measured sinkhole shown in number 12.

Figure 36

Figure 36 shows aligned composite sinkhole trends controlled largely by deep-seated rock structure and

lithologic contrasts. Such contrasts and resulting solution, although inferential, likely controlled the preglacial topography. Note that sinkholes are often located near but not precisely over approximate fault traces and lithologic contacts. The trace locations are shown as locations "approximate" owing to lack of bedrock exposures and limited and widely scattered borehole data.

Figure 37 (1979 photos)

Figure 37 shows bedrock geological data -- including synclines, faults, lithology, schistosity trends in the Meguma quartzite, and sinkholes -- glacier ice-flow direction and linear elements in the relief, as well as the location of the Westminer underground mine workings. Figure 37 also shows much the same NW and NE trends seen in Figure 36.

8 SYNTHESIS OF GEOLOGICAL DATA

A total of 37 figures have been assembled, mostly on 8 1/2-inch by 11-inch paper for easy reference. They provide regional and local geology background from which to infer trends, features, and correlations that bear on mine flooding and follow-up field reconnaissance, exploration, and testing.

In this synthesis, a number of inferences are presented below. They are based on office study of maps, reports, and airphotos without benefit of direct field

observation.

- Sinkholes tend to be clustered along preferred trends that seem to correlate fairly well with bedrock structures or with significant changes in the age and lithology of bedrock strata. It seems that most mine-inflow problems begin in saturated permeable overburden materials (surficial aquifers) that feed water into the underlying bedrock, which in turn cause trouble in mining.
- Sinkholes outlined on several figures -- large and well-expressed sinkholes, as well as small and poorly expressed ones -- are postglacial in age. However, some surface sinkholes may overlie earlier, ancestral sinkholes that are buried beneath glacial deposits and alluvium. Thus the mapped surface sinkholes date to less than about 13,000 years old whereas the soluble rocks in which they occur are over 300,000,000 years old. In addition, if over 100 sinkholes are identifiable in a mostly heavily wooded very young land surface, one might expect that there are a great many older buried sinkholes (paleokarst).

  On the other hand, several continental glaciations, attended by glacial erosion and stripping, may have removed much of the more highly solutioned preglacial evaporite topography.
- As noted above, the land surface in the Westminer area has undergone several (perhaps 4 or more) cycles of

glacial loading and unloading and uplift, creating a glacially modified complex system of valleys in the underlying bedrock. Preglacial and interglacial valleys were partially filled with pervious sand and gravel, then buried below younger glacial (e.g. impervious clay till) and postglacial alluvial sediments. I expect these preglacial and interglacial valleys occur in the Westminer area, although detailed geologic cross-sections, based on lines of drilled holes, have not been observed in data viewed and synthesized during this office study.

- The last continental ice sheet deposited clay-rich till over the pre-existing land surface, creating a widespread blanket of impermeable material. Bedrock knobs were buried beneath streamlined till forms(e.g. drumlins). These higher elevation areas and locations correlate with fewer sinkholes and correspondingly less evaporite solution and piping activity. In late glacial and early postglacial time, meltwater eroded much of the preexisting till in valleys and lowlands, then backfilled valley floors with stratified sand and gravel along with (clay and silt) sediments. Pervious glaciofluvial (running glacial meltwater) and low permeability glaciolacustrine (temporarily ponded glacial meltwater) sediments occur below about 105 ft (32 m) in the Westminer Canada mine area. Erosional and depositional events discussed above are inferential. Yet most are expected occurrences.

However, I have little feeling for geologic details relating to depth, thickness, extent, stratigraphy of overburden strata, and therefore locations of aquifers and aquitards in overburden in the Gays River valley and adjoining lowlands (below 32 m elevation).

9 FIELD EXPLORATION

As background, in the 20-year period 1956 to 1976, as hydrogeological consultants we supervised, installed, and evaluated over 150 groundwater developments, including dewatering projects for a variety of municipal and industrial clients and mostly for projects located on the Canadian Prairies. These projects required ballpark cost estimates covering what we planned to do, and how we planned to carry out our hydrogeological investigational programs. Most groundwater studies began with an office evaluation of map, report, and airphoto data -- such as I have done in this report. This initial study was often done before we visited the field to examine geologic features and collect data on farm well depths, static and pumping level depths, well yields, water quality, etc. Field reconnaissance usually involved talking to farmers and in some instances to a few knowledgeable individuals familiar with the geology or groundwater conditions in the area under study. Each groundwater investigation was a little different. Unit costs for drilling, well development and construction completion were obtained in advance of signing a contract

with the water-well driller as consultant on behalf of the owner.

I mention this because I believe one has to assess probable costs and chances of success or failure to determine the practicality of a potentially very expensive groundwater control exploration program that is likely to involve piezometer wells, pump wells, observation wells, dewatering wells, etc. Such costs have to be weighed against future benefits, potential mine hazard reduction, and so on.

I discussed several of these ideas with Vince Beckie, who supervised our groundwater investigations from 1960 to 1975. He then formed his own hydrogeological consulting firm and operated it from 1975 until his semi-retirement a short time ago. Several of Beckie's consulting projects involved mine groundwater dewatering and control assignments (Beckie's appendix, attached).

We agree that any field investigation program must consider information in the data synthesis in this report. But it should also be based on first-hand collection and analysis of on-site data and visual inspection, supplemented by discussions with individuals who have been closely associated with the project over a number of years. For instance, one must be careful not to set out an expensive drilling and dewatering program that has little chance of solving the problem.

Following are some field investigation activities one might consider. They should be guided by G. M. Meyer's hydrogeological study and his recommendations, which seem very good and pertinent to Vince Beckie and me:

- Examine potentially revealing geologic features in natural surface exposures, and in the faces of manmade excavations including roadcuts, gravel pits, mine portals and underground excavations.
- Examine existing groundwater control and monitoring systems, including well designs and other mine-inflow installations.
- Examine available stratigraphic logs from boreholes, with a view to classifying surficial and bedrock materials from the standpoints of origin and sequence of geologic events, material composition, and material permeability characteristics (aquifers/aquitards), etc.
- Determine whether or not selective geophysical tools and techniques (ground-penetrating radar, electrical resistivity, other methods) might be helpful in discovering locations of contacts of overburden over bedrock and changes in porosity and permeability of different bedrock units (e.g. cavities in evaporites). This is something on which an experienced geophysicist might be able to give advice (see G.M. Meyer report).
- Decide on a mine-inflow investigation based on the

above data synthesis, sinkhole locations, input from knowledgeable individuals about the history of mine-inflow problems, and some idea of probable cost.

10 CONCLUSIONS AND RECOMMENDATIONS

- The bedrock hydrogeology is complicated owing to as many as four different ages, compositions, and permeability characteristics of bedrock types and aquifers that come together in vicinity of the Pb-Zn ore body (Figures 1 to 18), and several possible overburden aquifers (Figures 19 to 25).
- The land surface surrounding Westminer Canada mine site is underlain by Windsor Group evaporites and by associated single isolated sinkholes and clusters of several sinkholes, many of which are presently active (Figures 27 to 37).
- Sinkholes in the region tend to preferentially follow contacts between different bedrock strata ages, diverse lithology (rock types), and geologic fracture structures (faults, joint zones, master joints). These contacts and tectonic fractures have largely controlled preglacial valley locations and, as a result, the loci of local infills of permeable sand and gravel in overburden strata in the Westminer Canada area.
- From the data synthesized for this report, it is difficult to predict where the next piping failure or sinkhole is likely to occur. To aid this

determination requires assembling scale-controlled cross-sections showing different bedrock and overburden hydrogeological units, water levels, and underground flow directions. Water levels can be used to prepare a potentiometric surface map. This map will help identify where the groundwater is most likely coming from, and where groundwater control installations will therefore be most effective.

Apparently no detailed plotting of the overburden stratigraphy has been undertaken. I am thinking of a series of geologic cross-sections, to suitable scale, showing mode and environment of sediment deposition, the positions of pervious geohydrological units (subtill, intratill, intertill, and supratill aquifers, the latter including outwash-delta and modern floowdplain alluvium), data on grain-size distribution, strata thickness, and permeability characteristics of aquifers and aquitards.

- Conclusions and recommendations by G. M. Meyer are well taken based on my understanding of the geology and mine-inflow problems at Westminer Canada.
- Once the necessary data have been collected and analyzed, risks have been assessed, and the probabilities of success or failure weighed, someone must try to decide whether the mine-inflow problem can be solved economically and safely. Assuming water problems can be handled with appropriate measures, someone should be made responsible for seeing that

groundwater measurements are made and monitored on an ongoing basis. Experience and continuity are key ingredients. A common situation at some mines we are familiar with is for those individuals in charge of mine inflow control problems to change jobs and responsibilities, interrupting the continuity. They may leave mine employment, or undertake a different job in the mine if things seem to be going along all right for the time being. The results of this lack of continuity can be devastating.

It will be necessary to plan ahead, preferably well in advance of water-inflow problems developing. These suggestions may have been in place; and it may be redundent to mention them here.

- It may be necessary to test certain approaches, designed to control the water problem, to see how well they work. Examples include the best locations for piezometer, dewatering wells, etc. (see Meyer, 1991).

Can the orebody be somehow compartmentalized (probably not?), and groundwater-control installations made in advance of mining operations?

- I discussed the problem at some length with Vince Beckie, retired consulting hydrogeologist, who headed our hydrogeology studies for 15 years (1960-1975). I asked him to summarize his impressions from reading my report, studying the 37 figures in it, and reviewing material in the reports by McKee and Hannon, 1982; Leggette, Brashears and Graham Inc., 1982; Martec

Limited, 1990; and G.M. Meyer, 1991. I have appended Mr. Beckie's comments and recommendations (Appendix A).

ACKNOWLEDGEMENTS

I am indebted to Tom Lamb, Westminer Canada, for forwarding several maps and reports dealing with past geological and hydrogeological studies of the Westminer Canada mine area (formerly Gays River Pb-Zn Mine).

I want to thank Robert Boehner, Gordon Adams, and Chris Cavanagh, Nova Scotia Mines and Energy, for phone-call discussions and for geological maps and reports showing the Westminer Canada and surrounding region.

I also obtained useful data from Pat Hannon, Mine Tech International Ltd; Professor Marcus Zentilli, Department of Geology, Dalhousie University; and Don Sangster, Geological Survey of Canada, Ottawa.

Wayne Clifton and Rick Yoshida, Clifton and Associates, Regina, were responsible for contacting me in regard to airphoto-mapping of sinkholes in the study area and for incorporating this information in an existing geological and hydrogeological data synthesis.

Finally, for discussion and suggestions, I would like to thank Vincent Beckie, hydrogeology consultant, semi-retired, formerly in charge of hydrogeological investigations in our firm for the period 1960 to 1975, and from 1975 to 1991 president of his own firm called Beckie Hydrogeologists Ltd., Regina.

APPENDIX A

By V.G. Beckie, P. Eng., P. Geol., hydrogeology consultant and former (1960-75) employee of J.D. Mollard and Associates, Limited. Based on discussions with J.D. Mollard, review of Mollard reports and figures, and perusal of three hydrogeology reports sent to this office by Mr Tom Lamb, Westminer Canada.

GENERAL COMMENT

I believe control of groundwater for the Westminer Canada mining operation will be difficult and costly. If done, it will require supervision by knowledgeable persons and also close monitoring. To me, it appears vital that groundwater recharge from surficial aquifers must be controlled. The information you synthesized and that is contained in other reports we discussed does not define aquifer extents, groundwater flow directions, nor aquifer contacts with the "trench" or with other permeable bedrock zones. In my view, acquisition of these kinds of data are a necessary first step to solving the mine-inflow problem.

Problems of mine flooding seem to be commonly caused by too little dewatering capacity. It is necessary to install standby wells and drains to handle peak flow conditions created by heavy rains or from runoff and infiltration from heavy snowmelt. Subsurface mine-inflow problems and their severity will gradually diminish if recharge through surficial aquifers to bedrock aquifers situated close to the orebody can be controlled.

RECOMMENDATIONS

1. There should be a well-thought-out program of test drilling to define the location(s), saturated thickness(es), and permeability characteristics of the surficial aquifer(s). Piezometers (50-mm in diameter) should be installed to obtain water level elevations. Slug or pumping tests should be run for permeability determinations. Water samples should be collected for chemical analyses and evaluation of their significance, if any.

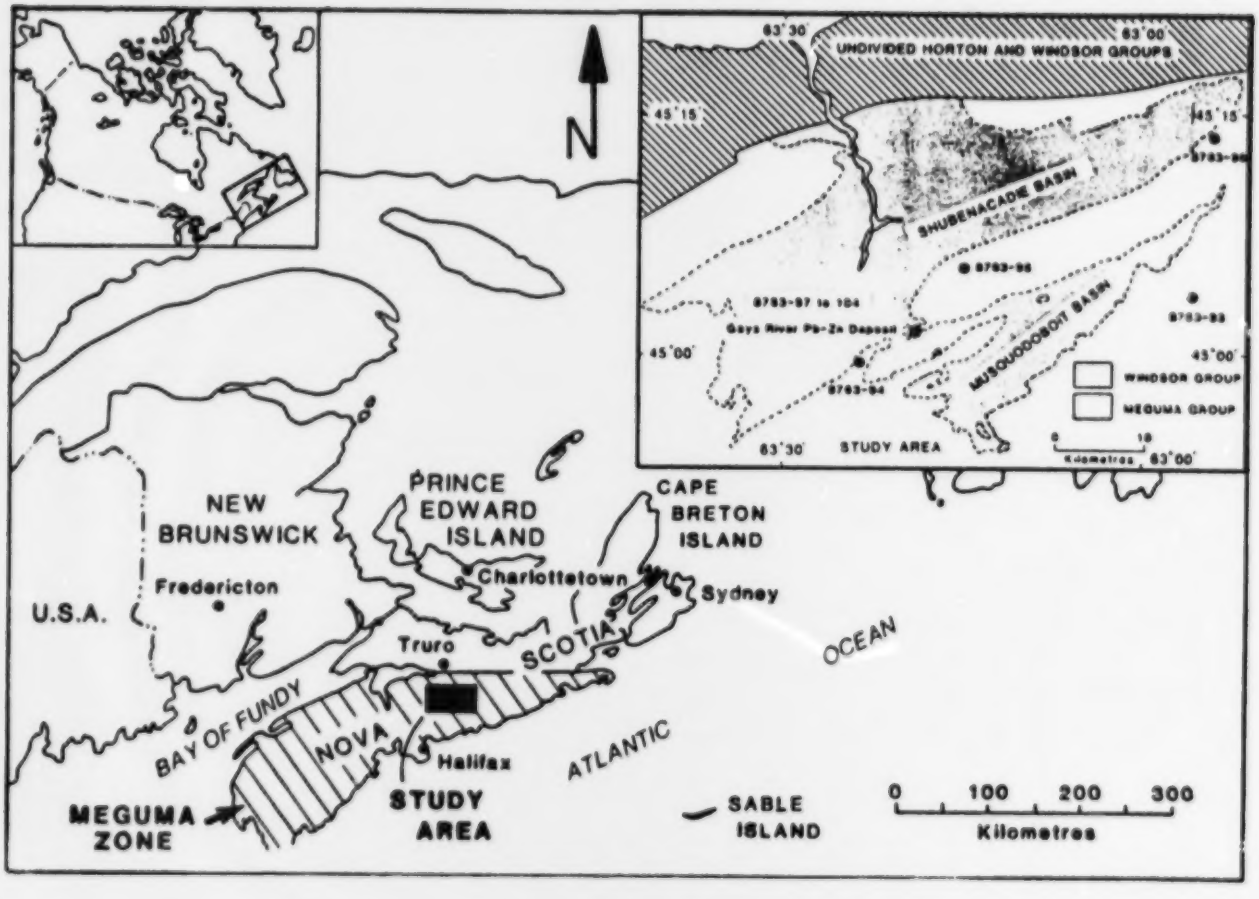
2. Use groundwater flow nets, flow directions, and water quality to isolate major recharge groundwater sources. Well clusters should be installed to trap overburden aquifer water before it recharges bedrock aquifers that create mine-inflow problems. Standby wells are required to handle peak periods of groundwater recharge.

3. Bedrock aquifer water problems will be lessened if a number of high-permeability, deep-pumping underground water source sites can be located and dewatered. Two methods of doing this should be considered: (a) surface exploration, and (b) underground exploration. One can try to locate high permeability zones by horizontal diamond drillholes from underground mine workings. Then, owing to potential well-clogging problems, consider vertical wells for dewatering

purposes. Surface exploration should be carried out in vicinity of selected sinkholes identified in the Mollard report figures, especially strategically situated sinkholes with respect to mine workings and high-grade ore deposits.

4. Geophysical exploration should be considered to identify high permeability overburden and bedrock structures. While this may prove unsuccessful, nevertheless it should be attempted because it might help identify the location and configuration of the bedrock surface because this influences the location of potential drill sites.

5. Cost of such program is important. It might be in the order of $300,000 to $1,000,000. The initial groundwater exploration program, with testholes and piezometers, will also provide essential information for a more definitive cost estimate.

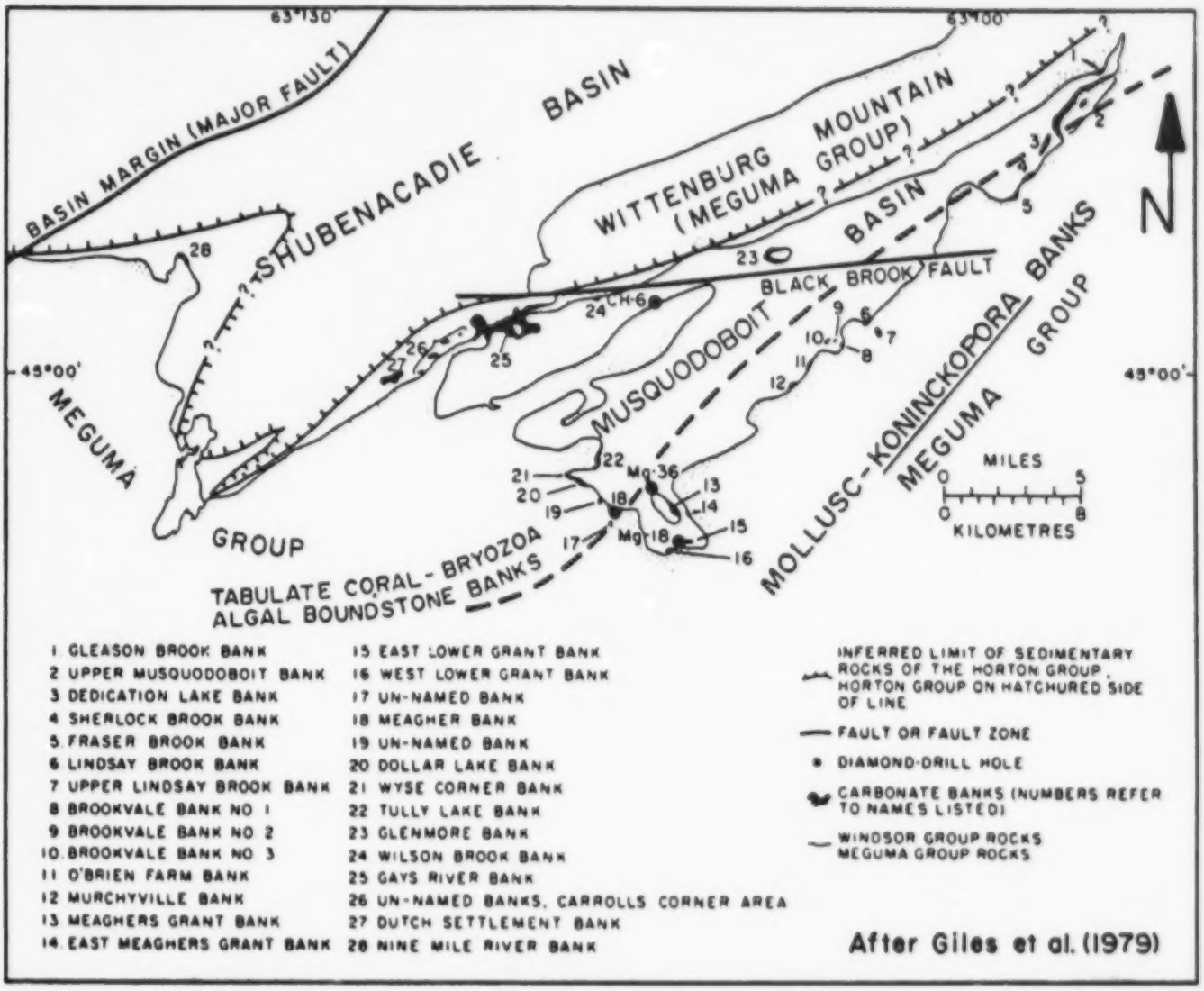


Geology modified after Giles and Boehner (1982).

KEY LOCATION MAP SHOWING GAYS RIVER Pb-Zn ORE DEPOSIT AND SHUBENACADIE AND MUSQUODOBOIT SEDIMENTARY BASINS

J.D. Mollard and Associates Limited
July, 1991

FIGURE 1

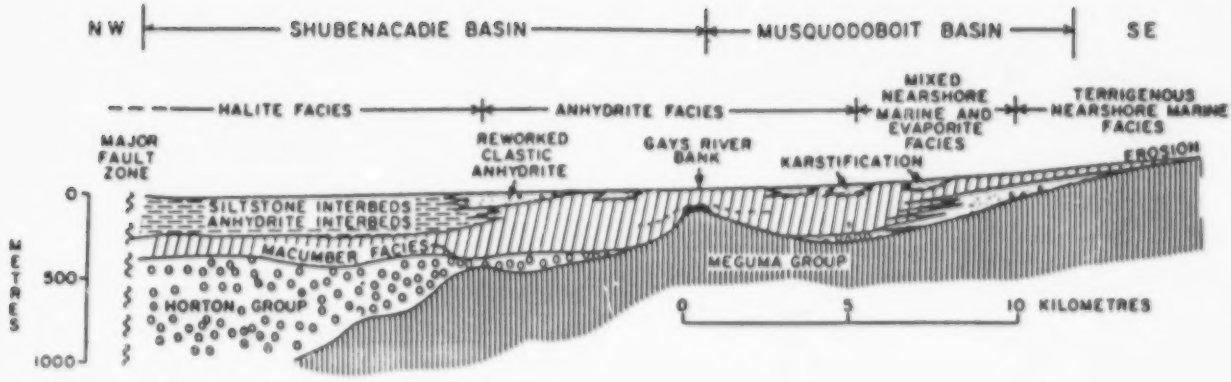


FROM : ***R.C. BOEHNER, P.S. GILES, D.A. MURRAY AND R.J. RYAN***

REGIONAL MAP SHOWING DISTRIBUTION OF 28 GAYS RIVER FORMATION BANKS IN CENTRAL NOVA SCOTIA (25 = GAYS RIVER BANK)

J.D. Mollard and Associates Limited
July, 1991

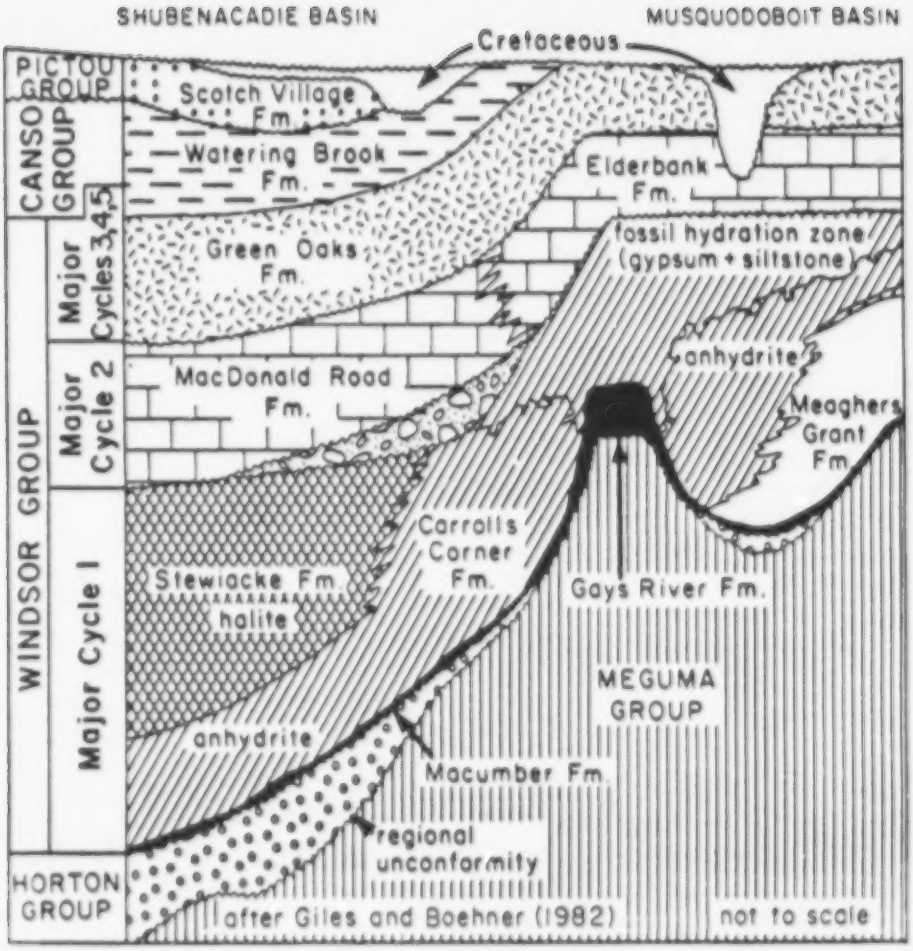
FIGURE 2



REGIONAL CROSS-SECTION SHOWING GAYS RIVER BANK BELOW ANHYDRITE FACIES WINDSOR GROUP MARINE EVAPORITES, AND ABOVE A MEGUMA GROUP RIDGE

J.D. Mollard and Associates Limited
July, 1991

FIGURE 3

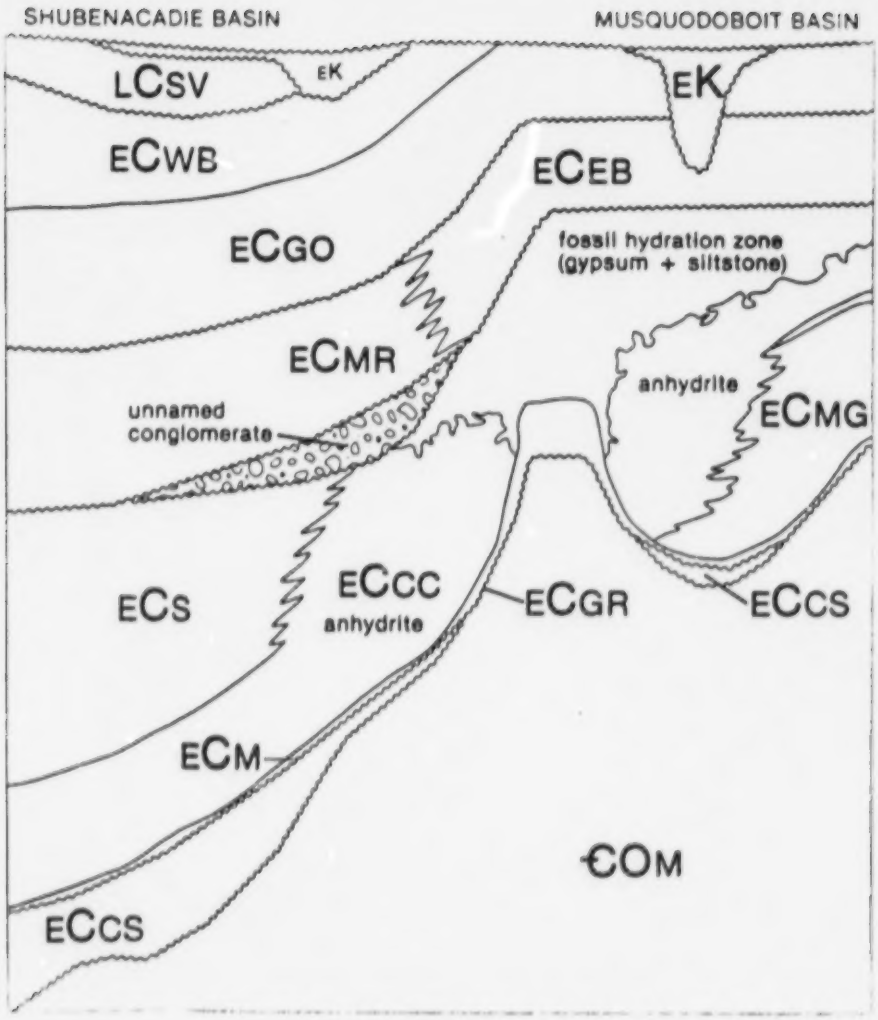


Diagrammatic structural-stratigraphic relations of the Windsor Group.

GAYS RIVER BANK LOCATION

J.D. Mollard and Associates Limited
July, 1991

FIGURE 4



P. S. Giles and R. C. Boehner
1982

CE OF NOVA SCOTIA, DEPARTMENT OF MINES AND ENERGY

HON. RON BARKHOUSE, MINISTER

JOHN J. LAFFIN, P.ENG., DEPUTY MINISTER

JOINT PROJECT
NOVA SCOTIA DEPARTMENT OF MINES AND ENERGY
AND
CANADA DEPARTMENT OF REGIONAL ECONOMIC EXPANSION

STRATIGRAPHIC FORMATION AND GROUP SYMBOLS WITH LITHOLOGY
(see figure 4 and 6)

J.D. Mollard and Associates Limited
July, 1991

FIGURE 5

LEGEND

MESOZOIC — CENOZOIC ERATHEMS

εK — Clay, sand, silt and lignite, mappable limits not clearly defined

angular unconformity

PICTOU GROUP

LCsv — *SCOTCH VILLAGE FORMATION*: sandstone, red and grey shale, siltstone

disconformity

CANSO GROUP

εCwв — *WATERING BROOK FORMATION*: grey mudstone and shale with intercalated gypsum, anhydrite and halite; evaporites most abundant in lower part of formation

WINDSOR GROUP

εCgo — *GREEN OAKS FORMATION*: maroon to reddish brown siltstone and fine grained sandstone, with intercalated marine limestone and dolostone; with associated anhydrite or gypsum in the Shubenacadie Basin

disconformity

εCMR / **εCEв** — *MacDONALD ROAD FORMATION* (εCMR): gypsum, anhydrite and minor halite, with interbeds of grey and maroon siltstone and sheet-like carbonate members; cyclic repetition of these rock units is characteristic

ELDERBANK FORMATION (εCEв): limestone, dolostone, conglomeratic sandstone and grey siltstone; very minor gypsum and anhydrite; cyclic repetition of these rock units is characteristic

disconformity

εCs / **εCcc** / **εCMG** / **εCM** / **εCGR** — *STEWIACKE FORMATION* (εCs): halite with minor intercalated anhydrite and siltstone; present in only the Shubenacadie Basin in the subsurface

CARROLLS CORNER FORMATION (εCcc): anhydrite, gypsum, with minor dolostone and mudstone in thin beds; includes undifferentiated shale and mudstone breccia with minor gypsum and anhydrite in proximity to the faulted northern margin of the Shubenacadie Basin

MEAGHERS GRANT FORMATION (εCMG): sandstone, siltstone and dark grey locally dolomitic shale; also arenaceous oolitic and stromatolitic dolostone; numerous interbeds of gypsum or anhydrite occur in the transition zone with the Carrolls Corner Formation; thinly intercalated red-brown to maroon sandstone, sandy shale and limestone commonly present, at or near the top, and termed the Lindsay Brook Marker Beds

GAYS RIVER FORMATION (εCGR): dolostone, minor limestone, thinly bedded, argillaceous and bituminous, locally thickly bedded and highly fossiliferous in mound-shaped deposits resting upon pre-Carboniferous rocks

MACUMBER FORMATION (εCM): limestone, in part dolostone, laminated and/or banded, peloidal, sparsely fossiliferous

PALAEOZOIC — CARBONIFEROUS

HORTON GROUP

εCcs — *COLDSTREAM FORMATION* (εCcs): reddish brown polymictic conglomerate and conglomeratic sandstone with minor dark grey shale; known mainly from the subsurface along the southern perimeter of the Shubenacadie Basin

disconformity

εCH — Undivided *HORTON BLUFF AND CHEVERIE FORMATIONS* (εCH): sandstone, conglomeratic sandstone, and minor shale, with a basal cobble conglomerate; includes minor coal in thin beds

DEVONIAN

angular unconformity

CAMBRO-ORDOVICIAN

MEGUMA GROUP

COм — *HALIFAX AND GOLDENVILLE FORMATIONS*: slate, meta-siltstone, meta-greywacke

SYMBOLS

- Rock outcrop: limestone, dolostone; commonly fossiliferous
- gypsum, anhydrite
- terrigenous sedimentary rocks
- Bedding; horizontal, inclined, vertical, overturned, tops unknown
- Geological boundary; approximate, dotted beneath Mesozoic cover
- Fault; approximate, dotted beneath Mesozoic cover
- Interpreted limit of the Horton Group, present on patterned side of line
- Thrust fault, barbs point down-dip
- Anticline and syncline
- Antiform and synform
- Anticline and syncline, overturned
- Asymmetric synformal anticline
- Fossil locality cited in text
- Spore locality
- Diamond-drill hole
- Principal reference section
- Mine or quarry; Pb-lead, Zn-zinc, Au-gold, gyp-gypsum, ls-limestone, cl-clay, sh-shale, SiO_2-silica sand
- Mine, abandoned
- Placer deposit, abandoned
- Mineral prospect; Pb-lead, Zn-zinc, Ba-barite

LEGEND AND EXPLANATION OF SYMBOLS IN FIGURE 5

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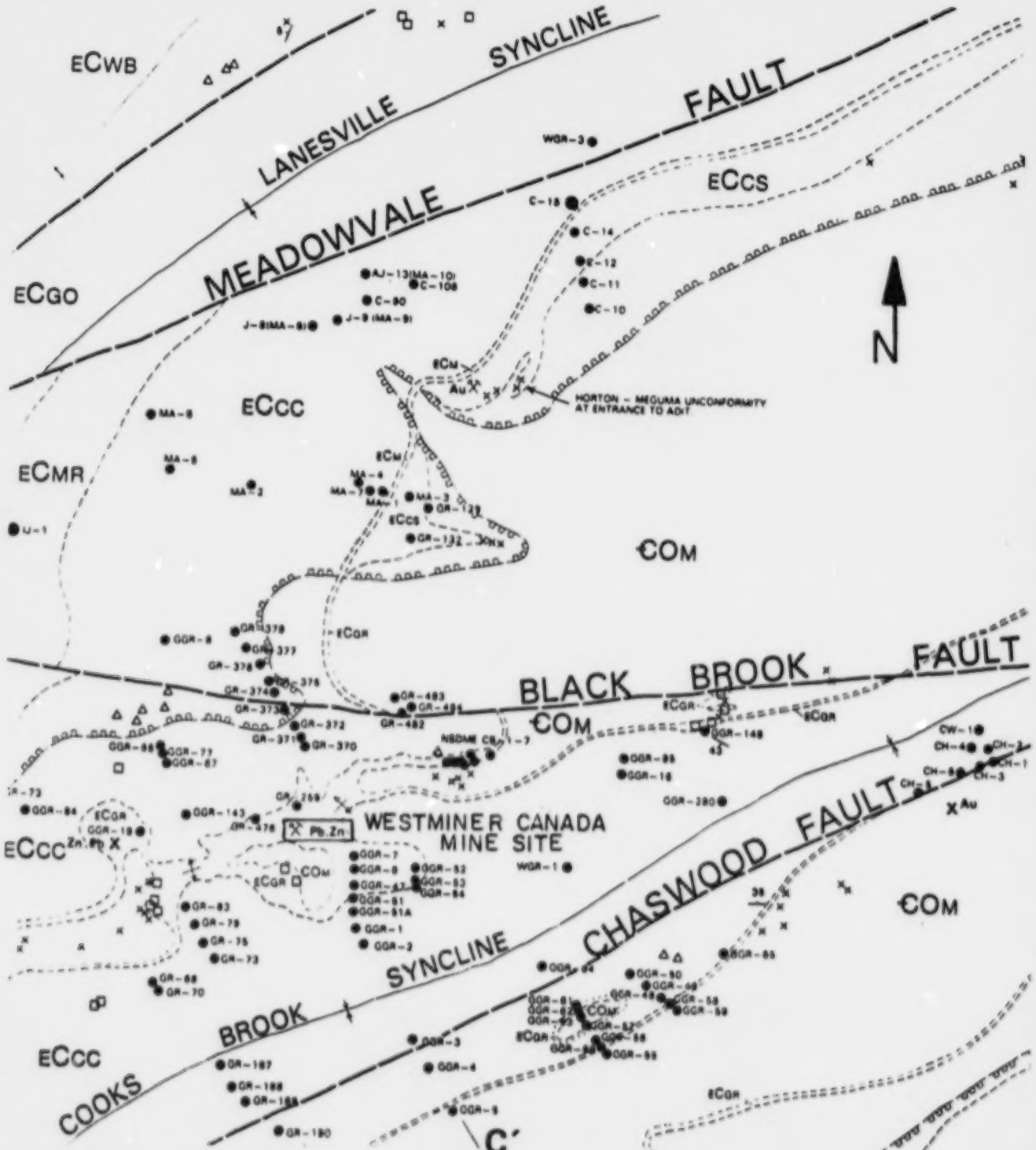
FIGURE 6



P. S. Giles and R. C. Boehner
1982

NOVA SCOTIA, DEPARTMENT OF MINES AND ENERGY

HON. RON BARKHOUSE, MINISTER

JOHN J. LAFFIN, P.ENG., DEPUTY MINISTER

JOINT PROJECT
NOVA SCOTIA DEPARTMENT OF MINES AND ENERGY
AND
CANADA DEPARTMENT OF REGIONAL ECONOMIC EXPANSION

BEDROCK GEOLOGY FOR AREA SURROUNDING WESTMINER CANADA Pb-Zn MINE SITE

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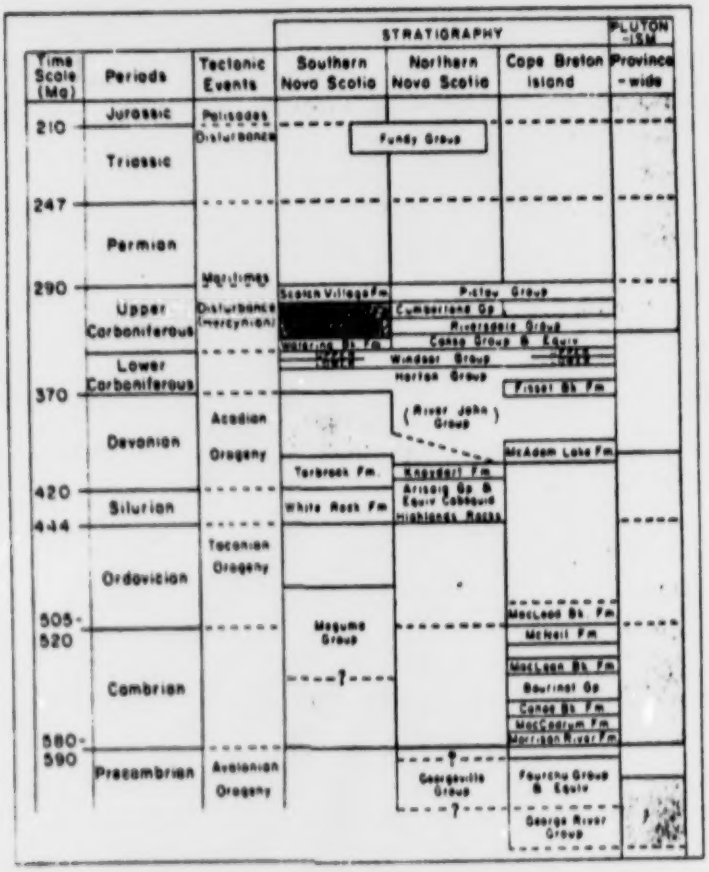
FIGURE 7



General stratigraphy and tectonic events of Nova Scotia.

Geology after Cook, 1973 and Keppie, 1977.

CHART SHOWING AGES OF TECTONIC DISTURBANCES IN NOVA SCOTIA
NOTE TWO EVENTS AFTER DEPOSITION OF THE WINDSOR GROUP EVAPORITES

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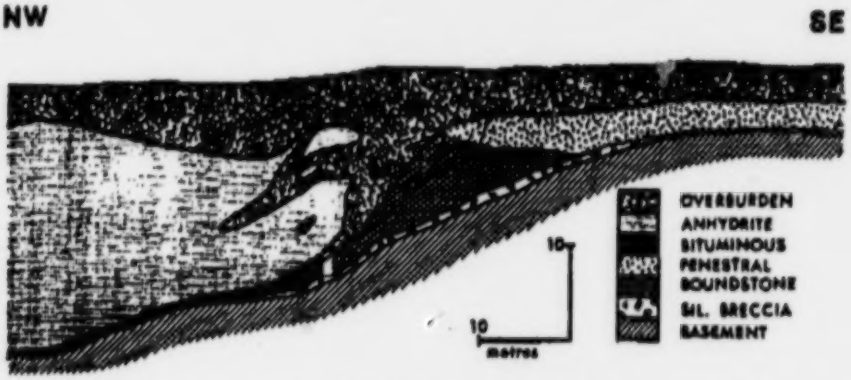
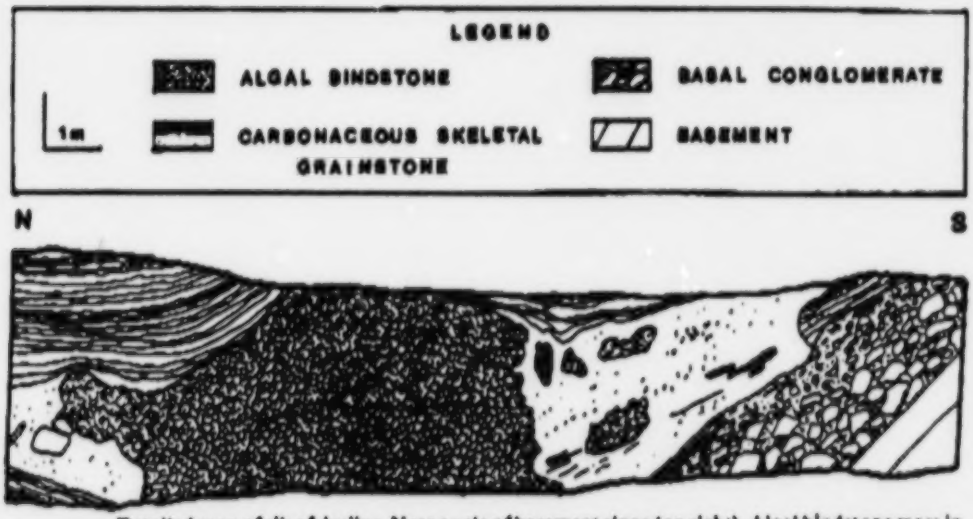
FIGURE 8

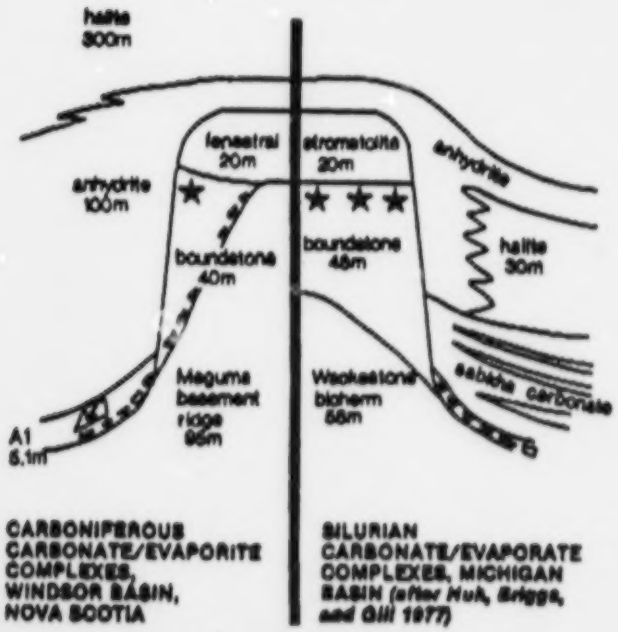


Schematic cross section of Gays River buildup after Hatt (1978). No vertical exaggeration.



Detailed map of rib of decline. Note angle of basement slope (on right). Algal bindstone mass in centre is inverted, facing down to left. Note that carbonaceous skeletal grainstone (off-reef deposit) cuts and folds over the boulder.

P.E. Schenk and B.L. Hatt



Comparison between Gays River Reef and pinnacle reefs of Michigan Basin.

THREE CROSS-SECTIONAL VIEWS OF THE GAYS RIVER CARBONATE REEF BUILDUP AND OVERLYING SEDIMENTS

J.D. Mollard and Associates Limited
July, 1991

FIGURE 9A

ABSTRACT: The Gays River Reef is one of many abnormally thick (110 m) carbonate buildups that occur in the lower Windsor Group. The buildup is located over a high basement ridge that bears spurs 90 m high and has slopes of 45° that are at least 0.3 km long. The ridge was blanketed with scree at the beginning of Windsorian time. Initially, marine transgression was rapid, but then it slowed to permit algal-dominated carbonate deposition to keep pace with rising sea level. Waters were of slightly high salinity that restricted invertebrates and encouraged blue-green algae. Off-bank areas were starved of sediment. As the rise of sea level slowed, the buildup changed from a reef to an island with broad intertidal and low supratidal zones. Dolomitization probably resulted from mixing between sea water and temporary fresh water lenses. Restriction of circulation and a high rate of evaporation led to evaporative drawdown, a drastic sea level drop of at least 100 m, and subaerial exposure of the carbonate buildup. The Gays River Reef was subjected to at least eight stages of diagenesis, mainly caused by karstic dissolution. Blocks of the lithified reef fell and were buried in storm-swept intertidal debris stabilized by prolific algal growth. Eventually the buildup was buried and encased in evaporites.

GEOLOGIC SETTING

The Gays River buildup is one of 28 known mounds in the Gays River Formation of the Musquodoboit and Shubenacadie basins (fig. 2) (Giles, Boehner, and Ryan, 1979). These basins are part of the Carboniferous Fundy Basin, a complex, post-Acadian horst and graben network in the Canadian Appalachians (Bell, 1958; Belt, 1968; Schenk, 1969). During the middle Carboniferous (Visean), the basin was flooded at least a dozen times, and cycles of carbonate, overlain by sulphate and thick fluvial and lacustrine redbeds, were deposited. Very thick halite beds and some potash occur locally. Nova Scotia at this time was near 10° south latitude (Roy and Robertson, 1988) and was midcontinental (Schenk, 1976). An arid or semiarid climate is evident from the abundance of evaporites and redbeds, the scarcity of plant debris, and the dwarfed invertebrates in dolostone (Schenk, 1969).

REEF SUBSTRATE—BASEMENT AND BASAL SILICEOUS BRECCIA

Description. The Gays River Reef straddles an easterly trending ridge in the underlying pre-Carboniferous rock (fig. 3). This ridge is coincident with an anticlinal crest exposing resistant quartz metawacke of the Meguma Group. The resulting ridge divides two Carboniferous basins—the Musquodoboit to the south from the Shubenacadie to the north (fig. 1). The study area is situated over the northwest limb of this anticline. This limb had been eroded prior to carbonate deposition into a number of northerly trending, irregularly spaced spurs ranging up to 90 m in height and 250 m in "wave length". The slopes on these spurs are controlled by strongly developed joint sets in the basement (085/45N and 150/70W) so that slopes are steep and stepped. Over short distances of 12 m, slopes reach 70°, and values of 40° are common. Northward-facing slopes are steeper than others because of the joint sets. These sets have created not only steep slopes, but also a basal, coarse breccia consisting of basement blocks. The breccia underlies both the reef and off-reef deposits (fig. 4).

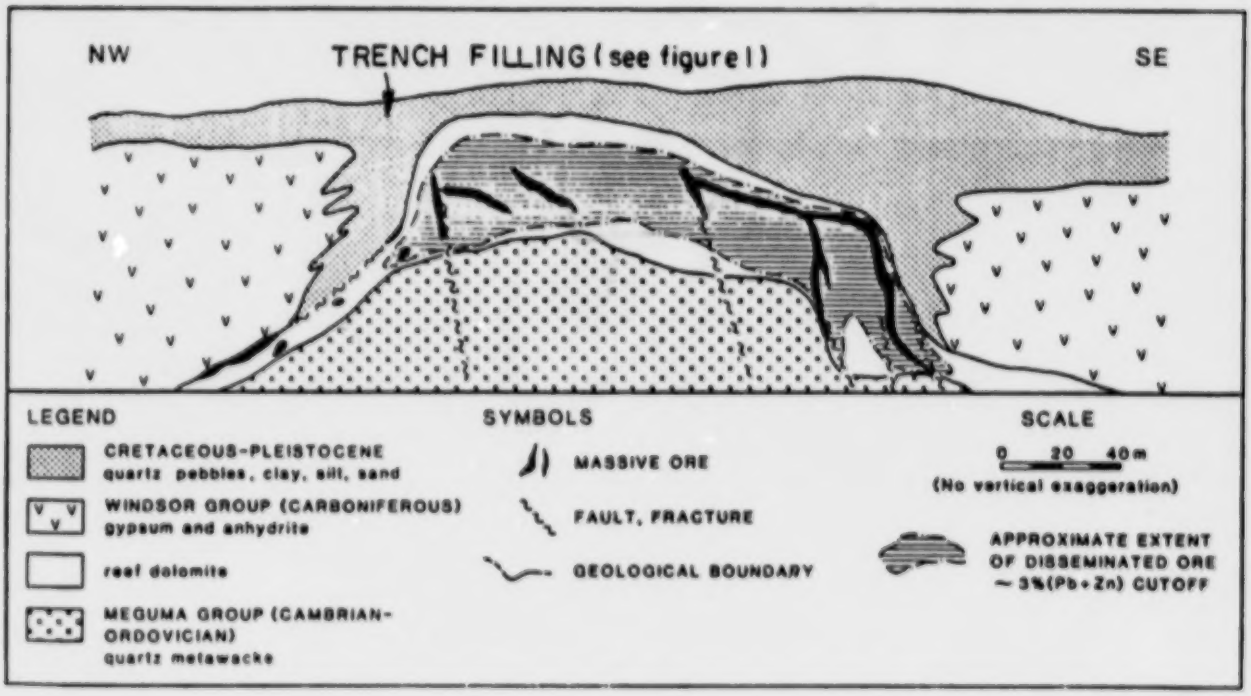
This basal breccia was produced mainly before but also during carbonate deposition. It is an oligomictic orthobreccia of angular, quartz-metawacke blocks of the Meguma Group. The average thickness is approximately 1 m with a maximum of 2 m, usually found in interspur reentrants. The unit is discontinuous and occurs as pods. The flanks of the basement ridge are marked in detail by joint-controlled steps; the pods typically occupy the "treads" of these steps. Clast sizes range from pebbles (fig. 6A) to boulders up to 2 m in outcrop diameter; shape ranges from subangular blocks to very rare rounded cobbles (smaller clasts are usually more angular). The matrix is composed of quartz sand or carbonate with minor amounts of lead and zinc sulphides. Overall, the breccia is graded vertically as to grain size—the coarser basal portion has a very siliceous matrix. Clasts are in grain support along the contact with the Meguma, but also occur apparently unsupported within the basal carbonate of both the reef and the flank deposits.

Depositional Environment of the Gays River Reef, Nova Scotia, Canada

Paul E. Schenk and Barry L. Hatt, 1984

J.D. Mollard and Associates Limited
July, 1991

FIGURE 9B



Cross section of the Gays River Pb–Zn deposit, illustrating the association of sulphide ore with a ridge of Cambro-Ordovician metasedimentary basement. Geology simplified from Akande and Zentilli (1984).

SMALL-SCALE CROSS-SECTION SHOWING GENERALIZED Pb-Zn ORE DISTRIBUTION IN CARBONIFEROUS REEF DOLOMITE STRATA OVERLYING A PALEOTOPOGRAPHIC RIDGE IN THE METASEDIMENTARY BASEMENT

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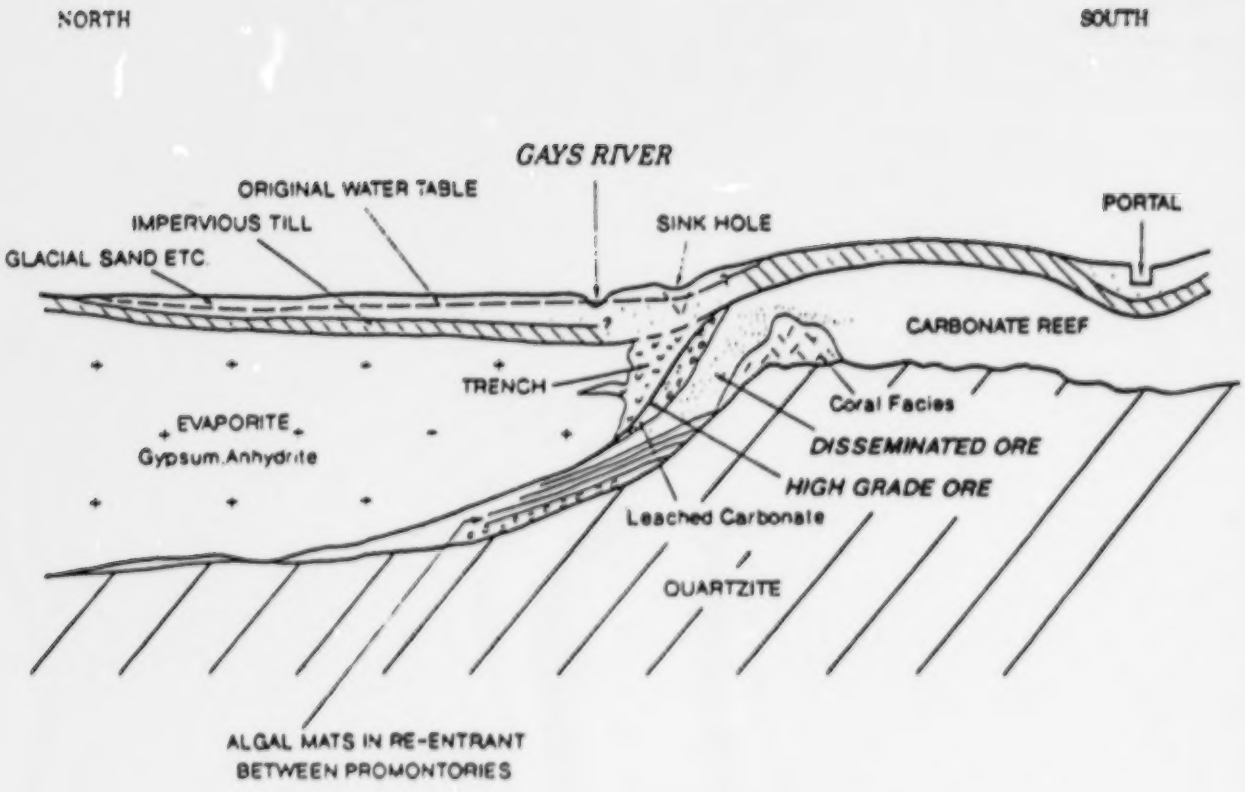
FIGURE 10



From: D.M. Mckee and P.J. Hannon, May, 1982

SCHEMATIC CROSS-SECTION SHOWING ORE IN CARBONATE REEF AND SURROUNDING SEDIMENTS

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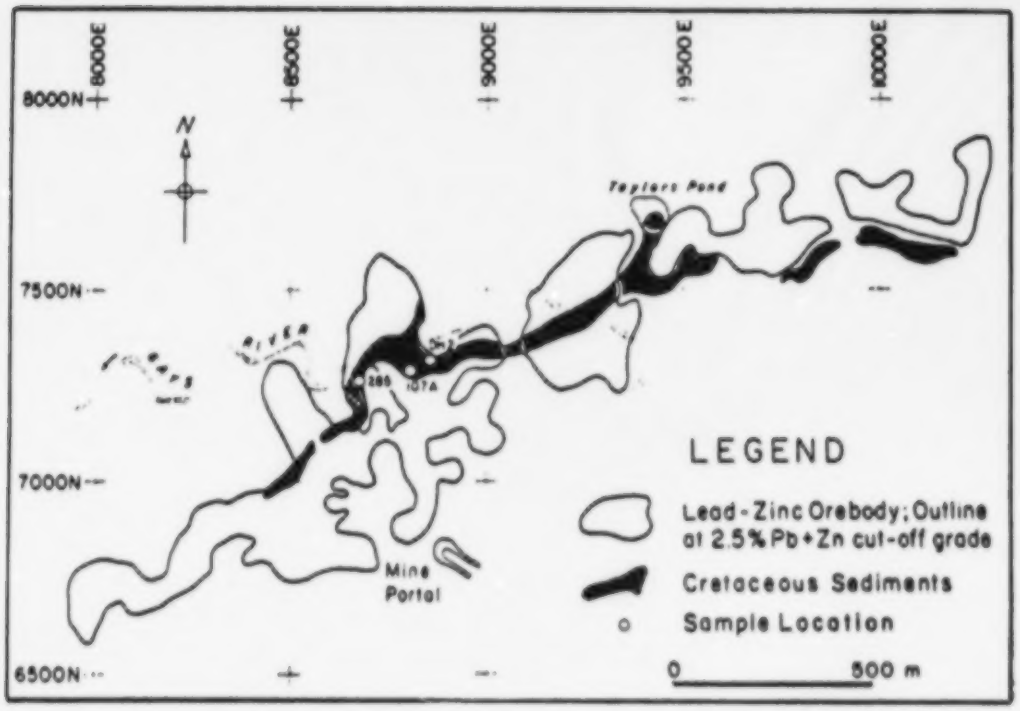
July, 1991

FIGURE 11



Map of the Gays River mine outlining the orebody and Cretaceous sediments in the "trench" system.

SMALL SCALE PLAN VIEW SHOWING Pb-Zn ORE BODY AND TRENCH CONTAINING CRETACEOUS AND PLEISTOCENE SEDIMENTS (see figure 10)

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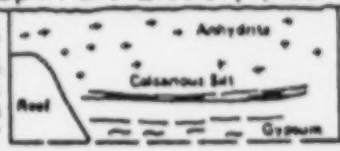
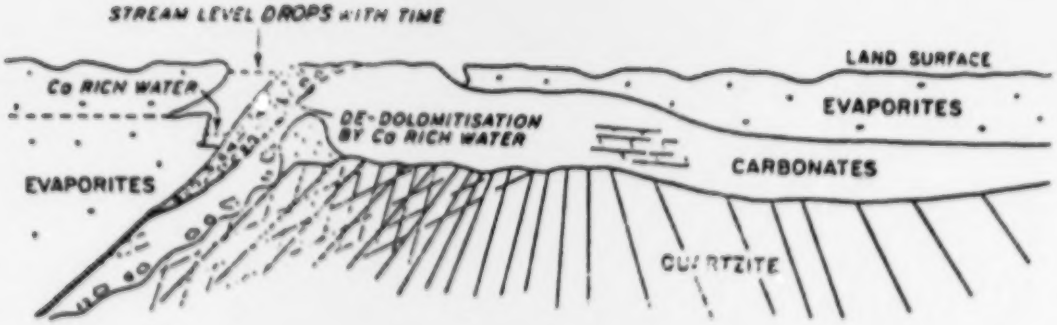
FIGURE 12

ERA	PERIOD	DIAGRAMATIC COLUMNAR SECTION	LITHOLOGY	HYDROLOGICAL CHARACT
CENOZOIC	QUATERNARY (Pleist-cene)		Recent stream sediment. Glacial till cut by outwash channel. Till, Bedrock	Glacial fluvial sediments - silt, sand and gravel cutting clay rich glacial till.	Glacial fluvial sediment homgeneous aquifer. Glacial till - soil piping
There is no record of Tertiary Sediments				
MESOZOIC	CRETACEOUS (Lower)		Trench eroded between carbonate and evaporites.	Trench: hard, dense clay, clayey silt, and gravel.	Trench - soil piping Cavernous zones piping.
There is no record of Pennsylvanian, Permian, Triassic, or Jurassic Sedimentation				
Uplift and Erosion, (Post Lower Mississipian, Pre Middle Cretaceous)				
PALEOZOIC	MISSISSIPPIAN Gays River Formation		Anhydrite with Gypsum & argillaceous limestone/dolomite horizons.	Calcium Sulphate Salts	Impervious (but soluble)
		Erosion ?			
	Windsor Group		Reef complex micritic, algal, clastic, and coral facies.	Dolomitic limestone dedolomitized vuggy carbonate at the trench contact	Fracture porosity
		Folding, Faulting, Uplift and Erosion			
	CAMBR-ORDOV. Meguma Gr. Gold'vl. Frm.		Blocky, massive quartzite to greywacke beds with slate horizons.	Quartz sand, minor chloride	Essentially impervious

STRATIGRAPHIC UNITS
GAYS RIVER MINE
(after McKee and Hannon, 1982)

J. D. Mollard and Associates Limited
July, 1991

FIGURE 13



GEOLOGY OF GAYS RIVER MINE

CRETACEOUS PERIOD 65 TO 135 MILLION YEARS AGO

TIME OF UPLIFT AND EROSION OF REEF

(from: McKee and Hannon, 1982)

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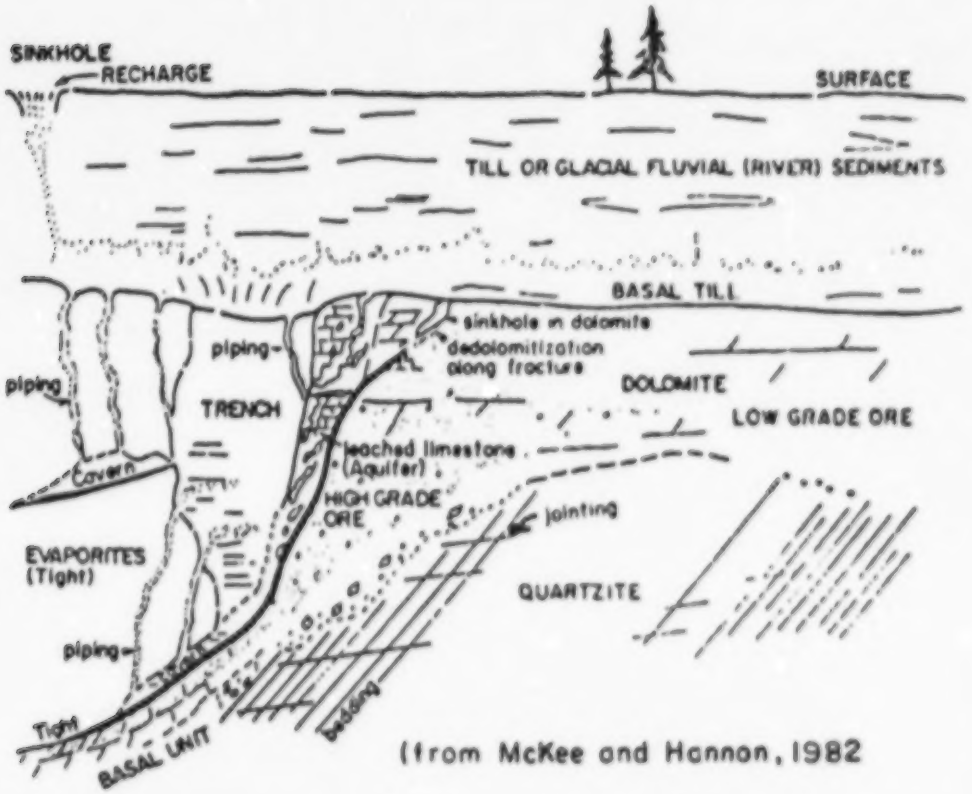
FIGURE 14



(from McKee and Hannon, 1982

GAYS RIVER MINE

HYDROGEOLOGICAL UNITS

Note location of trench sediments with respect to evaporites, high-grade ore, and hypothetical piping passageways

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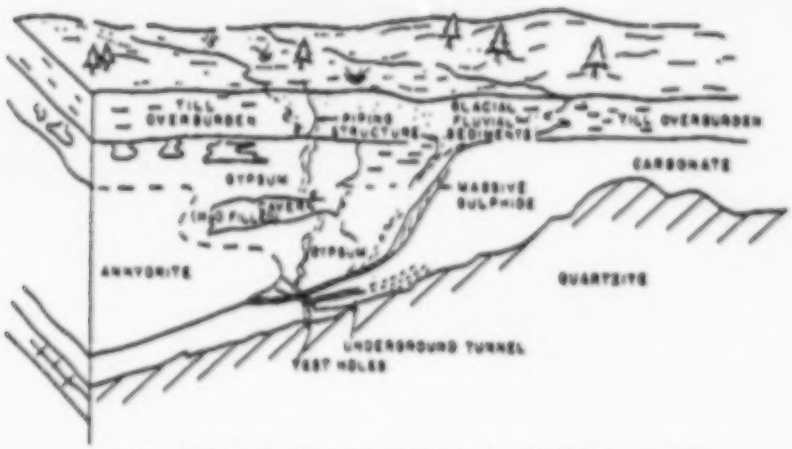
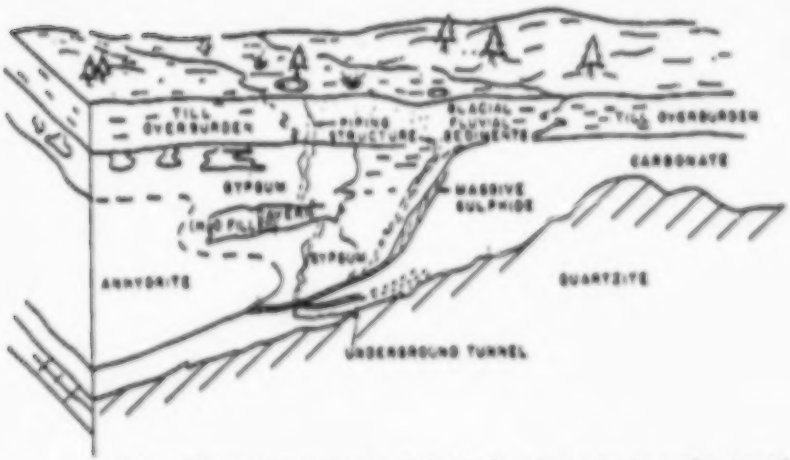
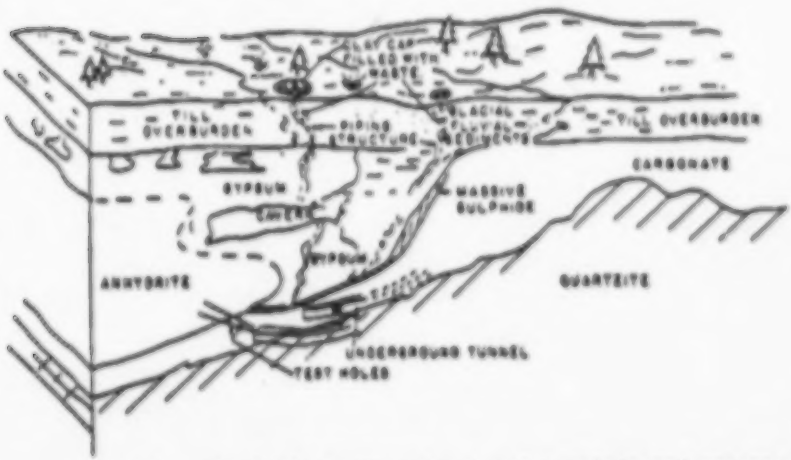
FIGURE 15



(a): The underground heading is advancing in ore, testholing along the way. The testholes miss the piping structure.



(b): The water-bearing "pipe" is exposed when the round is blasted. The heading floods with water, sand and mud. Sinkholes form on the surface.



(c): The drift is pumped out and a reinforced concrete bulkhead is built. The heading must go through waste to bypass the water.

INDICATED SEQUENCE OF MINE-FLOOD EVENTS
(from McKee and Hannon, 1982)

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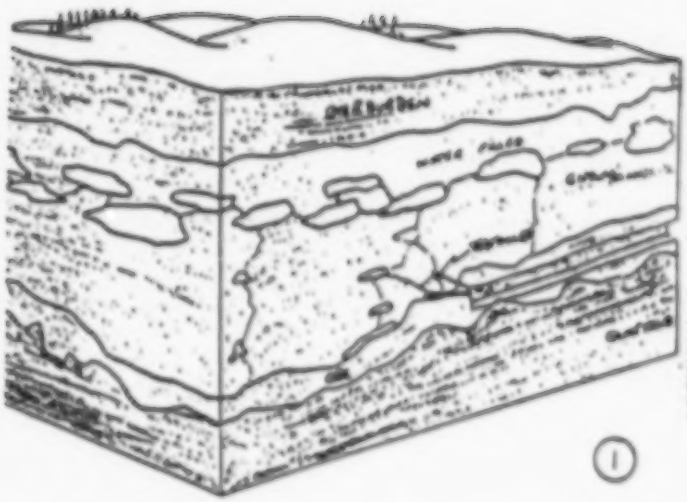
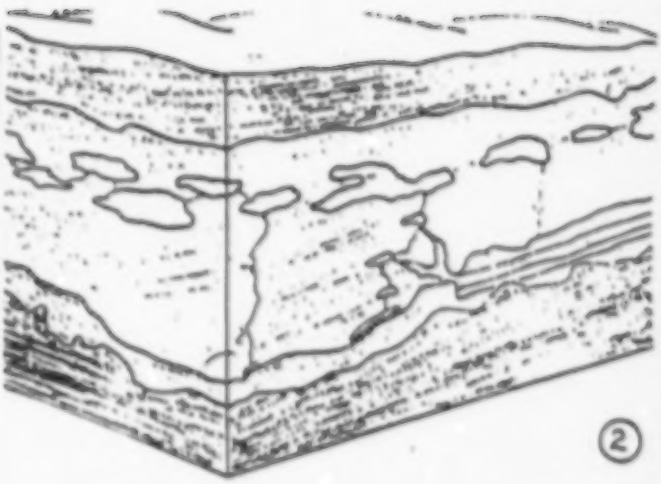
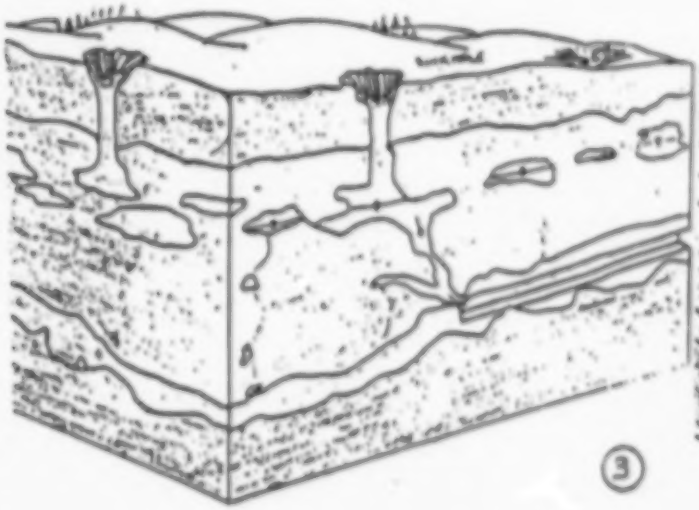
FIGURE 16



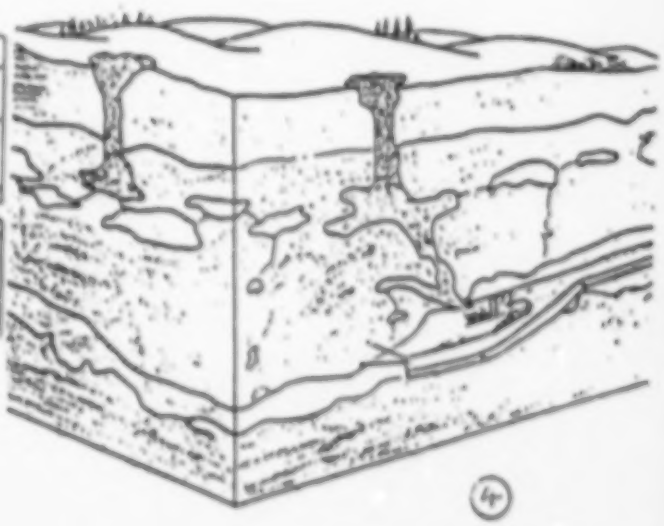
The U/G heading is advancing in ore, testholing along the way. The testholes miss the piping in the gypsum.



The water bearing pipe is exposed after the round is blasted.



The heading floods with water, sand and mud. A sinkhole forms on surface.



The drift is pumped out and a reinforced concrete bulkhead is built. The heading has to go through waste to bypass the water.

ANOTHER BLOCK DIAGRAM OF EVENTS PORTRAYED IN FIGURE 16
(after McKee and Hannon, 1982)

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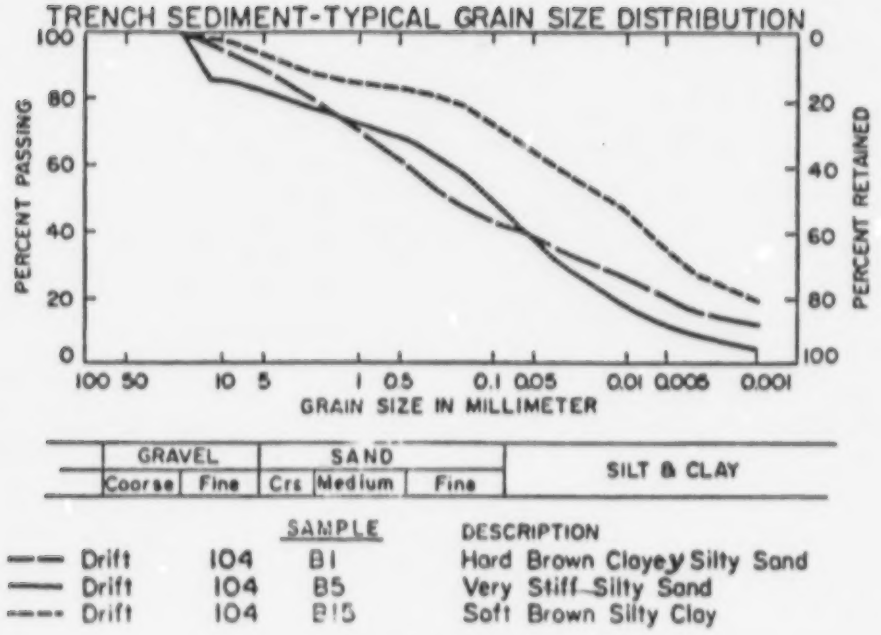
FIGURE 17



(from McKee and Hannon, 1982)

GRAIN-SIZE ANALYSIS OF TYPICAL "TRENCH" SEDIMENT

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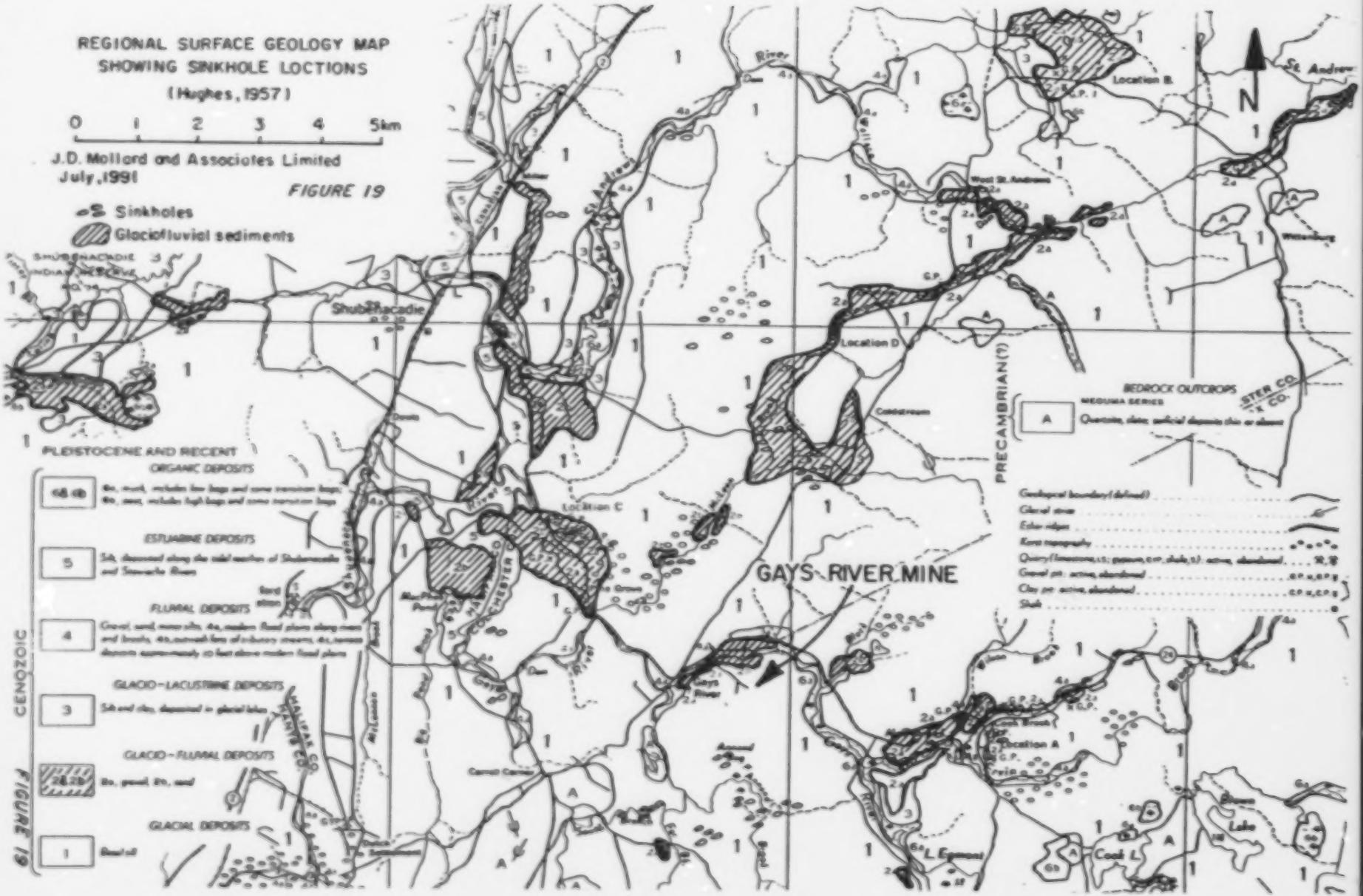
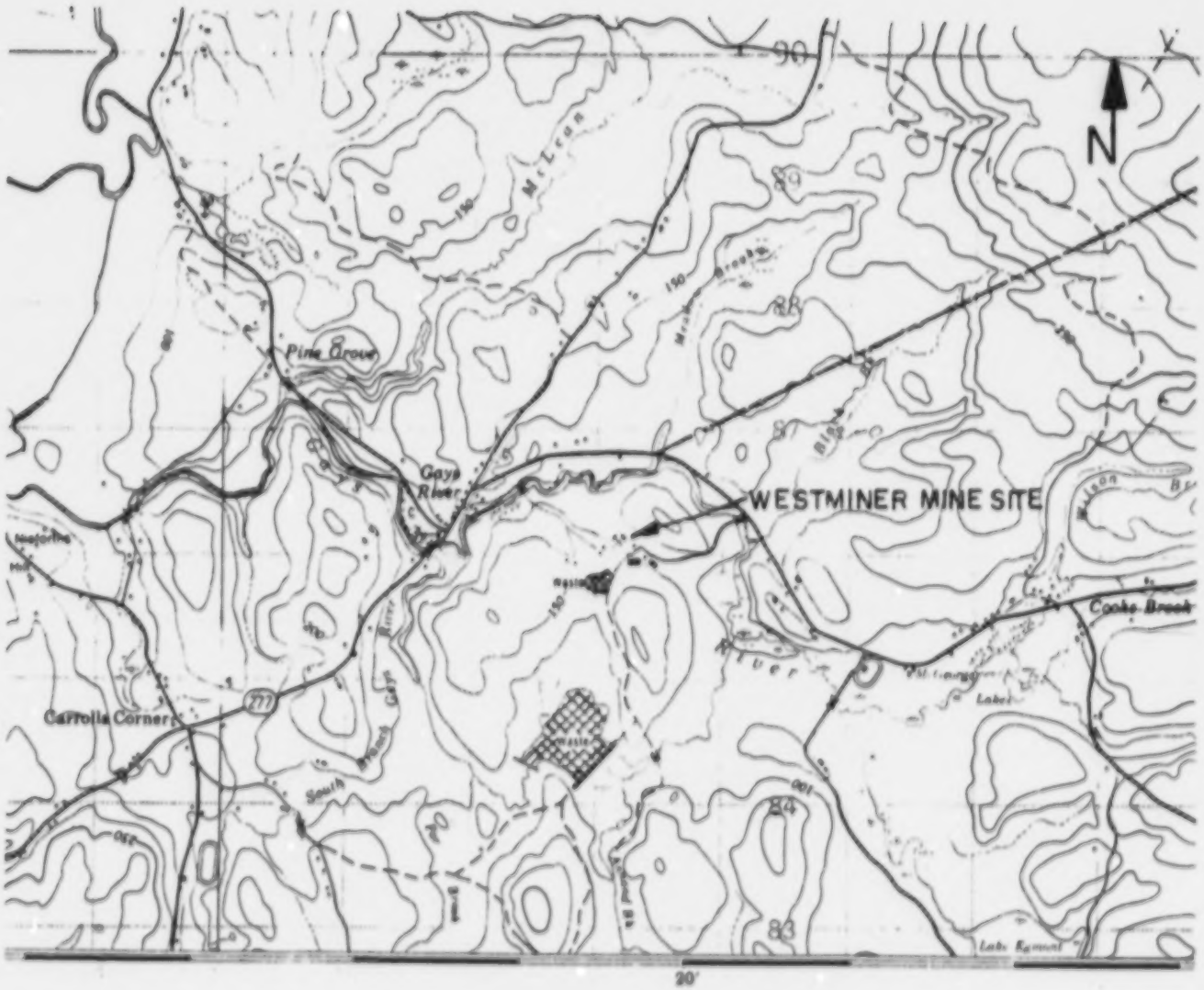
FIGURE 18


REGIONAL SURFACE GEOLOGY MAP
SHOWING SINKHOLE LOCTIONS
(Hughes, 1957)
0 1 2 3 4 5km
J.D. Mollard and Associates Limited
July, 1991
FIGURE 19
Sinkholes
Glaciofluvial sediments
GAYS RIVER MINE
Shubenacadie
St. Andrew
Location A
Location B
Location C
Location D
PRECAMBRIAN(?)
BEDROCK OUTCROPS
MEGUMA SERIES
PLEISTOCENE AND RECENT
ORGANIC DEPOSITS
ESTUARINE DEPOSITS
FLUVIAL DEPOSITS
GLACIO-LACUSTRINE DEPOSITS
GLACIO-FLUVIAL DEPOSITS
GLACIAL DEPOSITS
CENOZOIC
FIGURE 19



TOPOGRAPHIC MAP OF WESTMINER MINE SITE AND SURROUNDING AREA

Contour interval =50 ft (15.2 m)

Metres 1000 0 1000 2000

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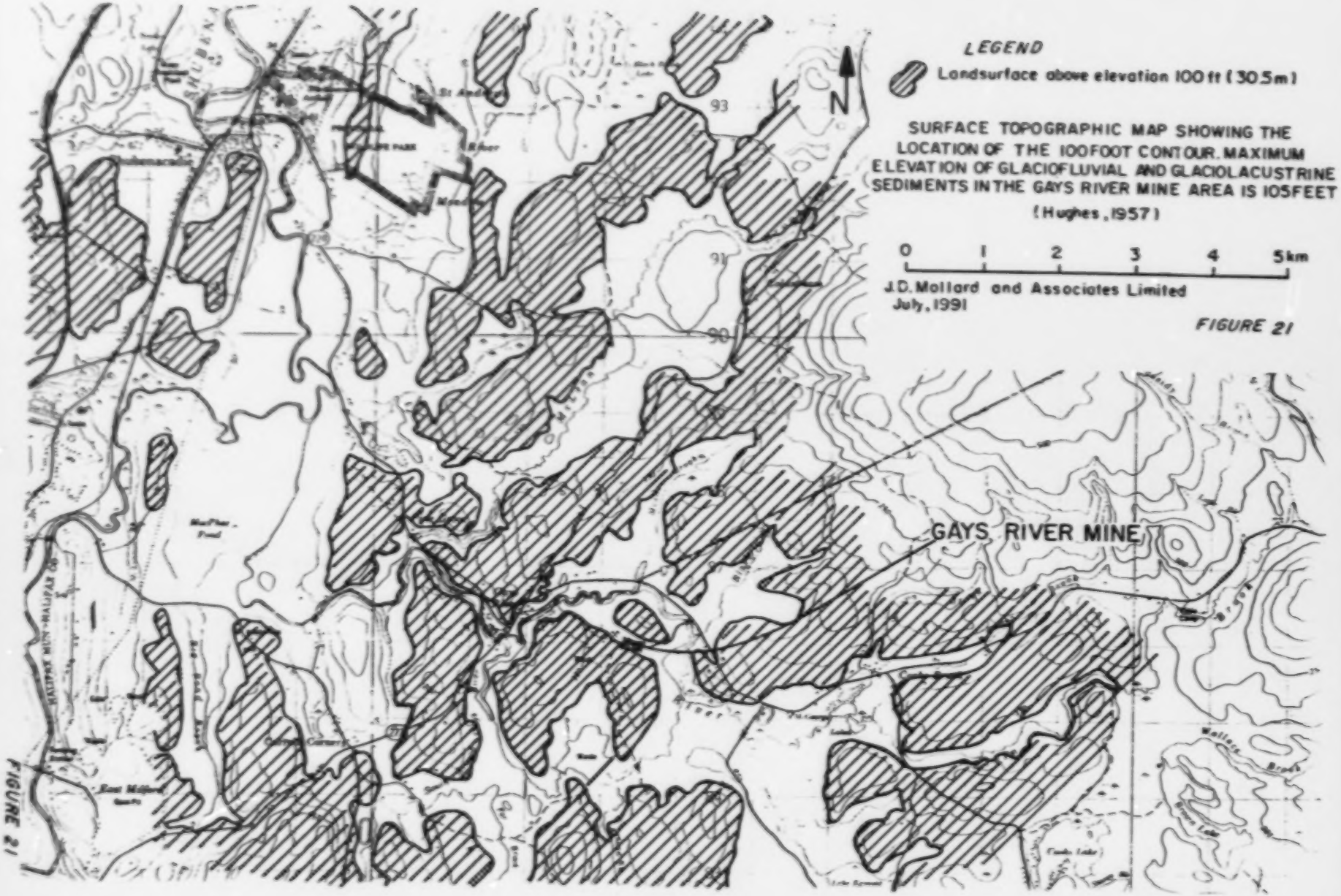
FIGURE 20



SURFACE TOPOGRAPHIC MAP SHOWING THE LOCATION OF THE 100 FOOT CONTOUR. MAXIMUM ELEVATION OF GLACIOFLUVIAL AND GLACIOLACUSTRINE SEDIMENTS IN THE GAYS RIVER MINE AREA IS 105 FEET (Hughes, 1957)

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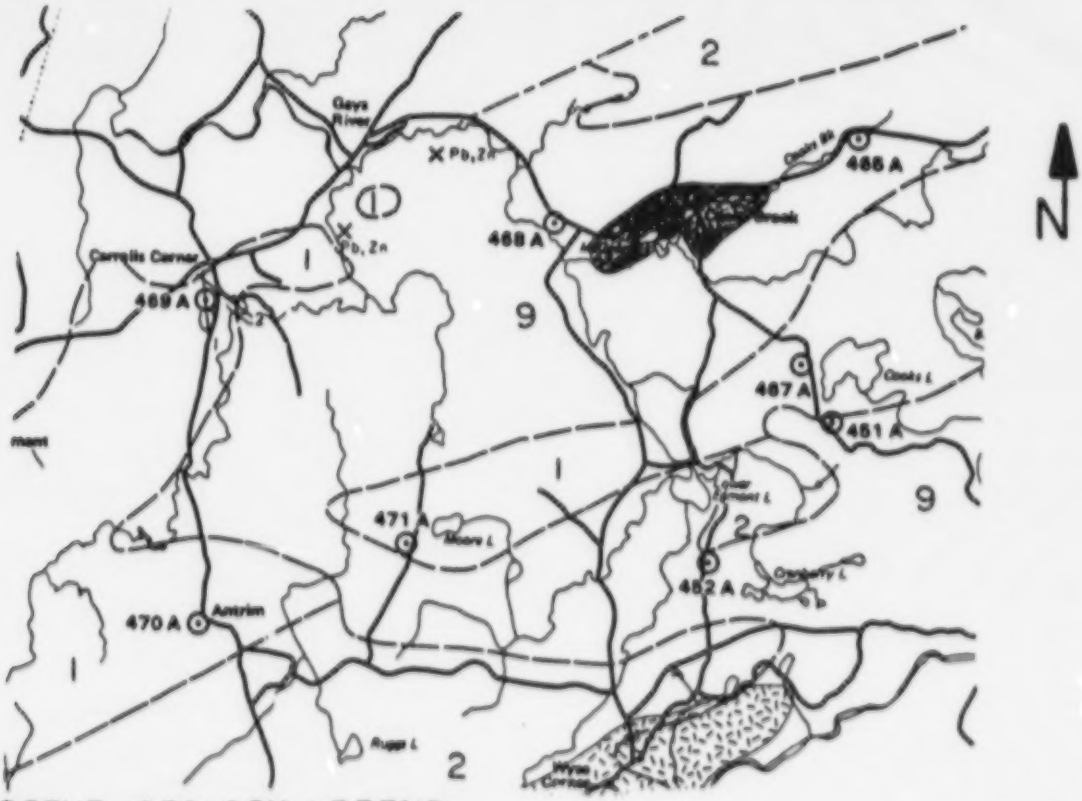
FIGURE 21

FIGURE 21



PLEISTOCENE GEOLOGY LEGEND

UNIT *	DESCRIPTION OF UNIT AND FACIES	GEOMORPHIC AND TOPOGRAPHIC EXPRESSION	THICKNESS
Glaciofluvial Deposits	Water sorted, bedded, sand, silt and gravel.	Terraced valley trains, hummocky kame fields, sinuous ridges (eskers) and outwash.	5 m to 30 m variable
Lawrencetown Till (Ablation)	Red-brown, loose, sand till.	Hummocky ablation moraine, knob and kettle topography.	3 m average
Lawrencetown Till	Crimson-ochre red, moderately compact clay till with a facies gradation to a brown, compact, sand-silt till. Clay till matrix (sand 25%, silt 40%, clay 25%), sandy till matrix (sand 50%, silt 35%, clay 15%)	Ground moraine, commonly fluted, over lowlands; drumlins displaced over the upland region underlain by quartzite and slate. Occurs also as drift tails and mantling bedrock cores. Facies are a result of comminution of local bedrock with the parent red clay till down ice and peripherally in drumlin fields (Grant, 1963)	Ground moraine 8 m average 35 m maximum Drumlins 25 m maximum

BEDROCK GEOLOGY

EARLY CARBONIFEROUS

WINDSOR GROUP

9 *Marine and marginal basin sedimentary rocks*

EARLY ORDOVICIAN (?)

2 *HALIFAX FORMATION: slate, schist, minor quartzite*

1 *GOLDENVILLE FORMATION: quartzite, gneiss, greywacke, minor slate*

0 5 Kilometres

SHEET 3

PLEISTOCENE GEOLOGY

EASTERN SHORE REGION

NOVA SCOTIA

1979

(from R.R. Stea and J.H. Fowler, 1979)

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FIGURE 22

LEGEND

Morainic deposits and drumlins : clay-rich till

Glaciofluvial* (outwash-deltaic) sand, silty sand, gravelly sand; thin clay seams

Postglacial floodplain alluvium: silt, sand, minor clay

*Probably includes some deep-water glaciolacustrine sediments as well as glaciofluvial deposits

WESTMINER MINE SITE AND SURROUNDING AREA OVERBURDEN DEPOSITS

(from G. Meyer, February, 1991, Hydrogeology Report)

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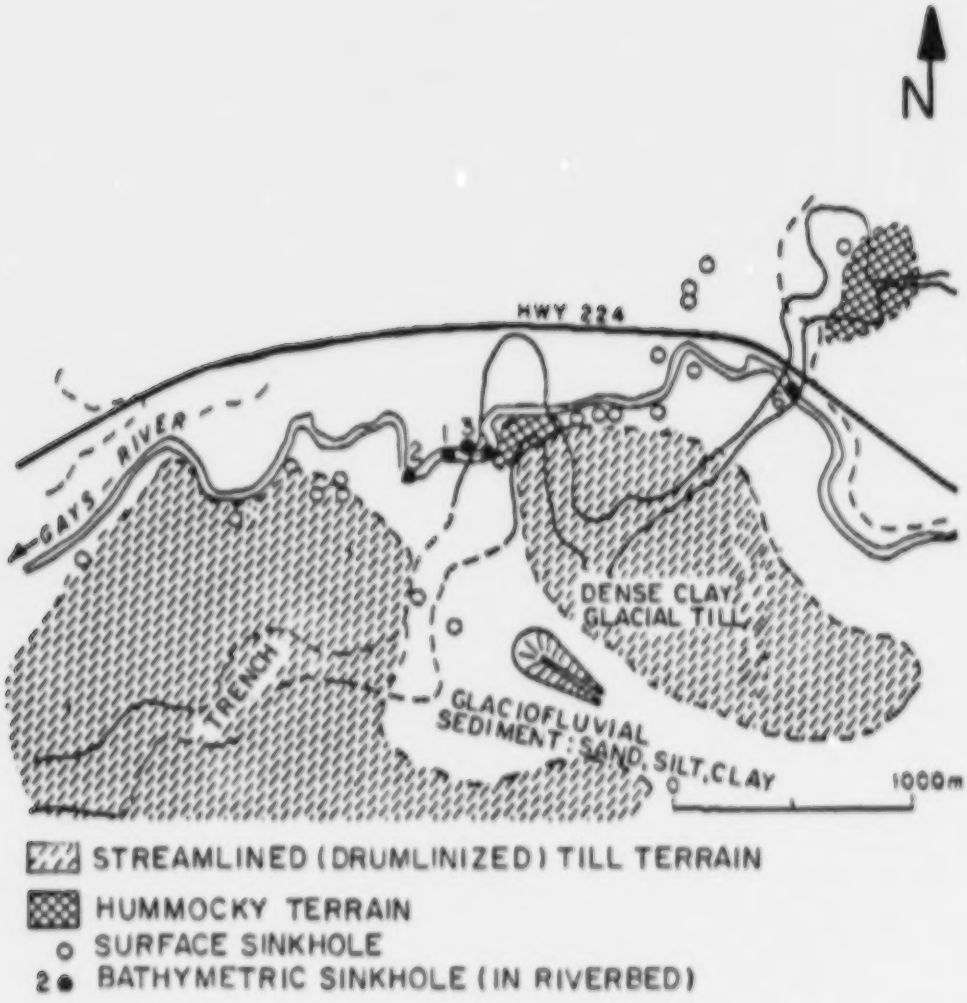
FIGURE 23



SINKHOLES IN RELATION TO SURFICIAL GEOLOGY
(from Leggette, Brashears and Graham, Inc in Phase I: Hydrogeologic Investigations, Gays River Mine, April, 1982)

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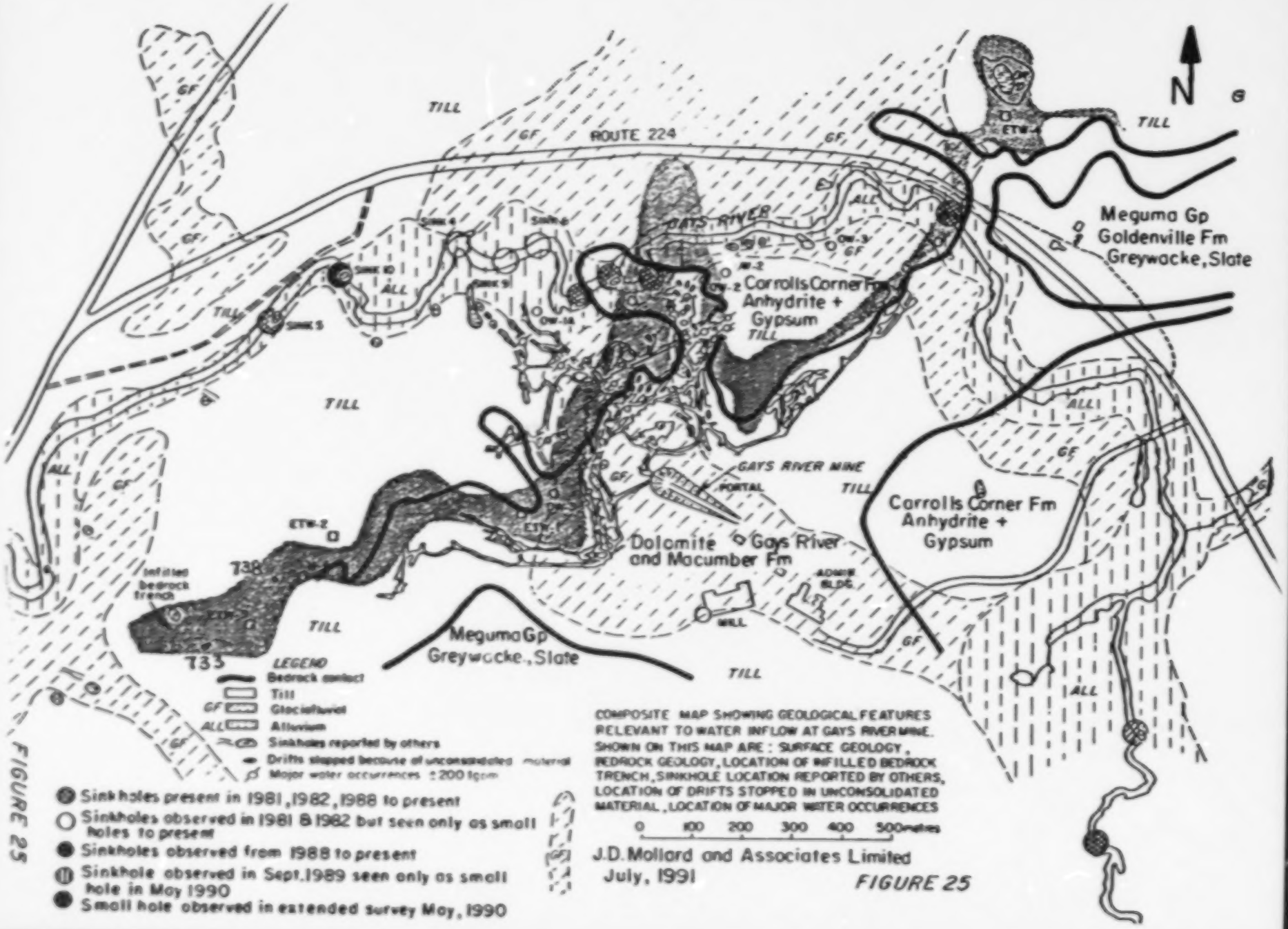
FIGURE 24



COMPOSITE MAP SHOWING GEOLOGICAL FEATURES RELEVANT TO WATER INFLOW AT GAYS RIVER MINE. SHOWN ON THIS MAP ARE: SURFACE GEOLOGY, BEDROCK GEOLOGY, LOCATION OF INFILLED BEDROCK TRENCH, SINKHOLE LOCATION REPORTED BY OTHERS, LOCATION OF DRIFTS STOPPED IN UNCONSOLIDATED MATERIAL, LOCATION OF MAJOR WATER OCCURRENCES

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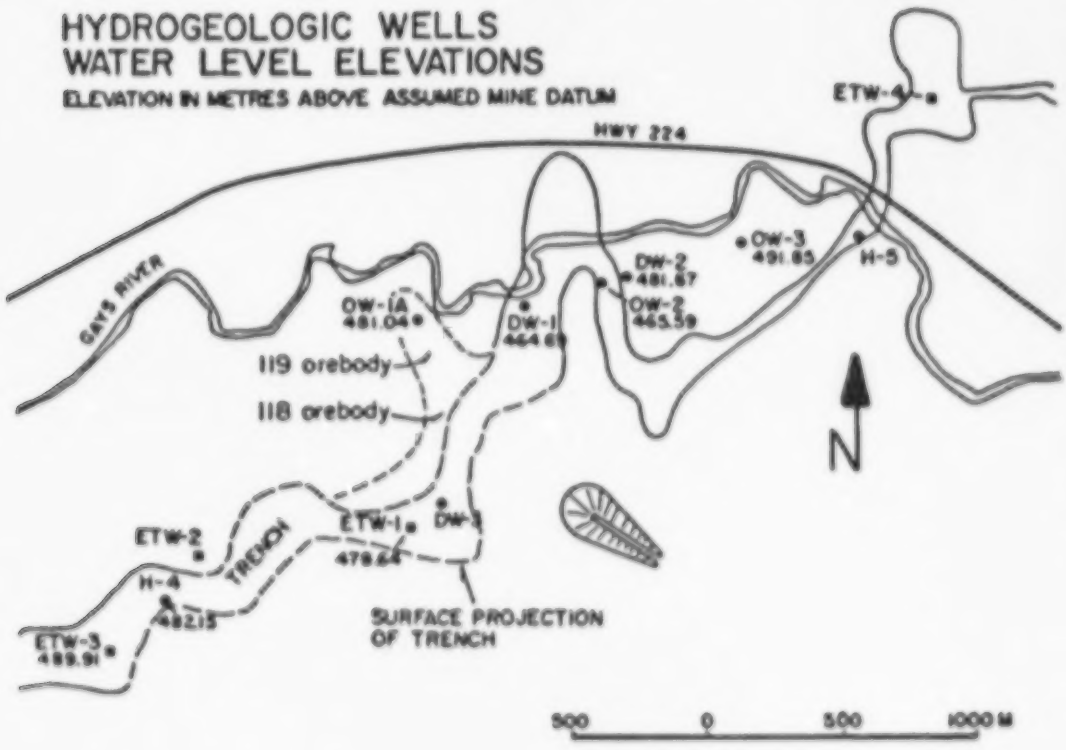
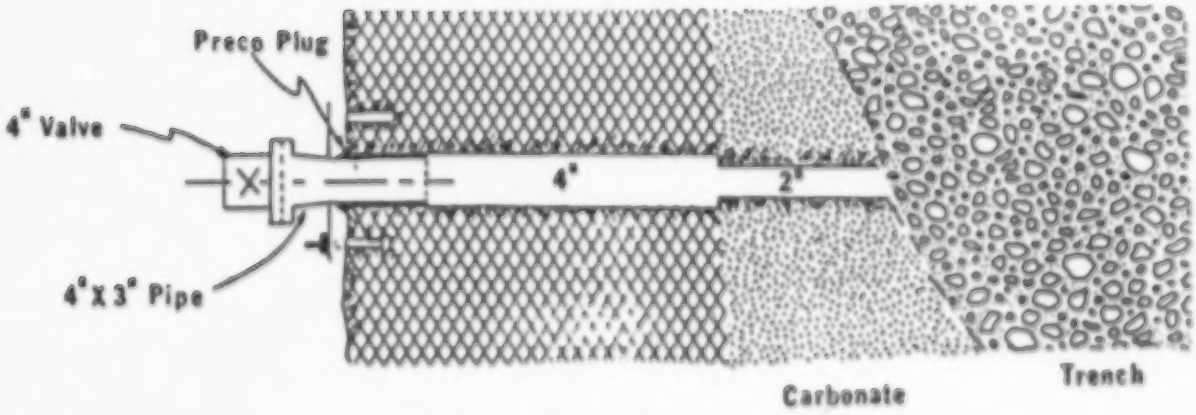
FIGURE 25

FIGURE 25



Observation and Test Well Layout



UNDERGROUND DEWATERING WELL

OBSERVATION AND TESTWELL LAYOUT AND UNDERGROUND DEWATERING WELL (DRAINHOLE)

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FIGURE 26

1979 PHOTO (B&W)

SOLUTION / STRUCTURAL SURFACE FEATURES
(PREFERENTIAL PERMEABILITY)

0 1 2 3 4 5km

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FIGURE 27

SINKHOLES SOUTH OF WESTMINER MINESITE

1954 PHOTO (B&W)

0 500 1000 1500m

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FIGURE 28

LEGEND

● Incipient sinkholes

1954 PHOTO (B&W)

INCIPIENT SINKHOLES

0 500 1000 1500m

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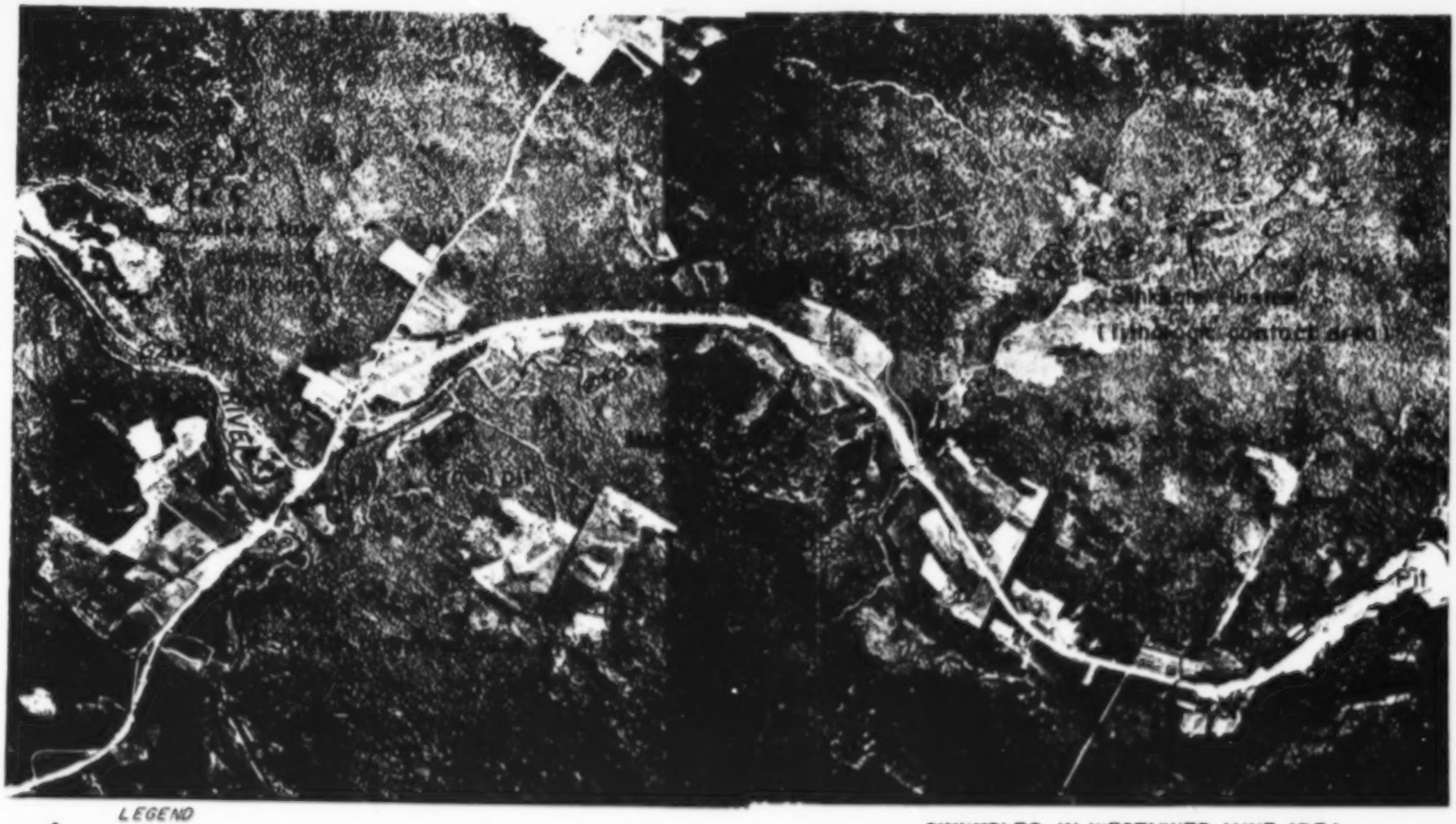
FIGURE 29



LEGEND

Sinkholes

SINKHOLES IN WESTMINER MINE AREA
1954 PHOTOS (B&W)

0 500 1000 1500m

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FIGURE 30

Sinkholes

1990 PHOTO (COLOUR)
CLASSIC LARGE SINKHOLES AND INFERRED
SMALLER SINKHOLES ON GAYS RIVER FLOODPLAIN

0 500 1000km

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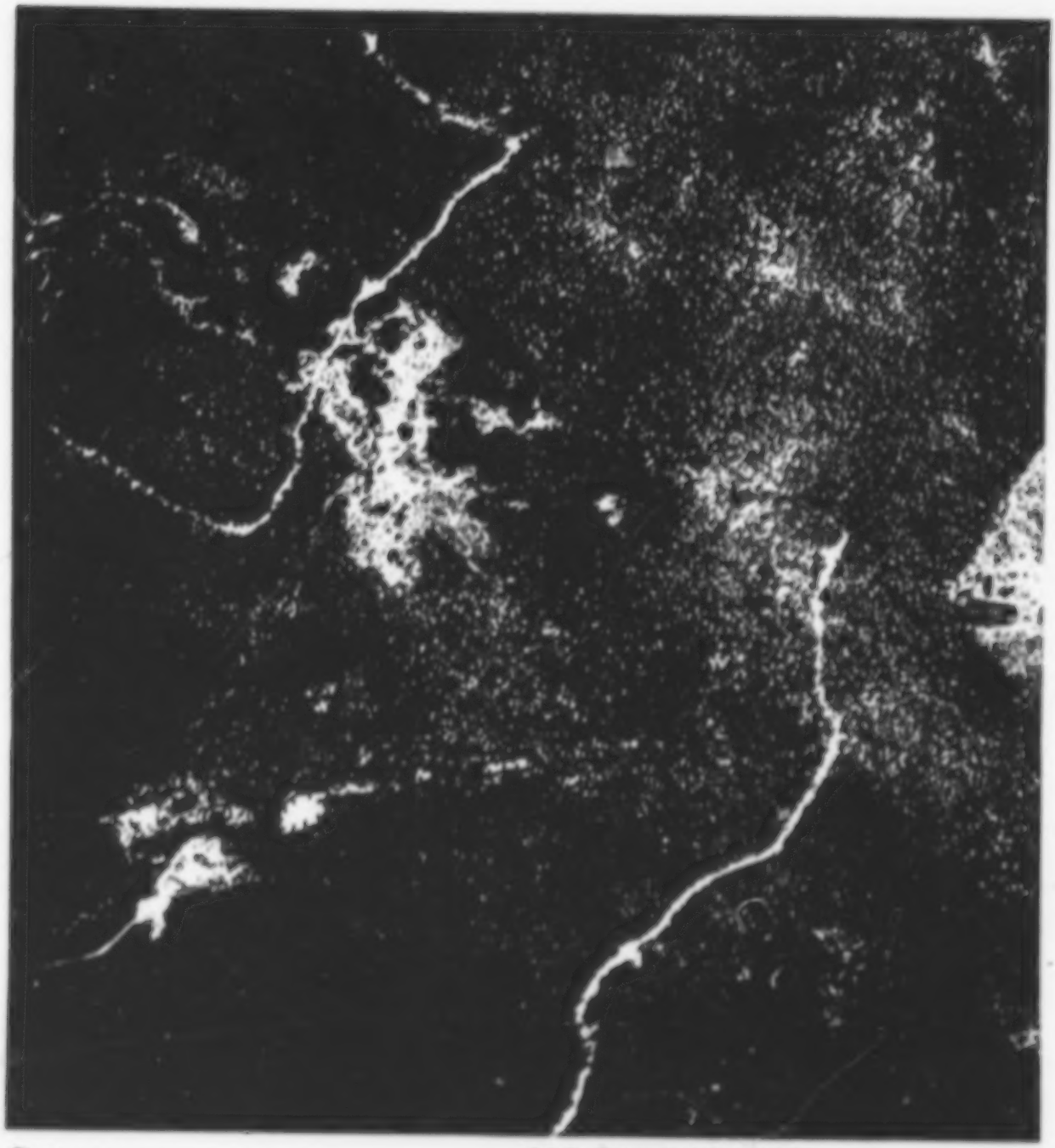
FIGURE 31



Sinkholes

1990 PHOTO (COLOUR)

PROMINENT SINKHOLES ALONG INFERRED KARST VALLEY AT LITHOLOGIC CONTACT ZONE NORTHEAST OF WESTMINER MINE SITE

0 500 1000km

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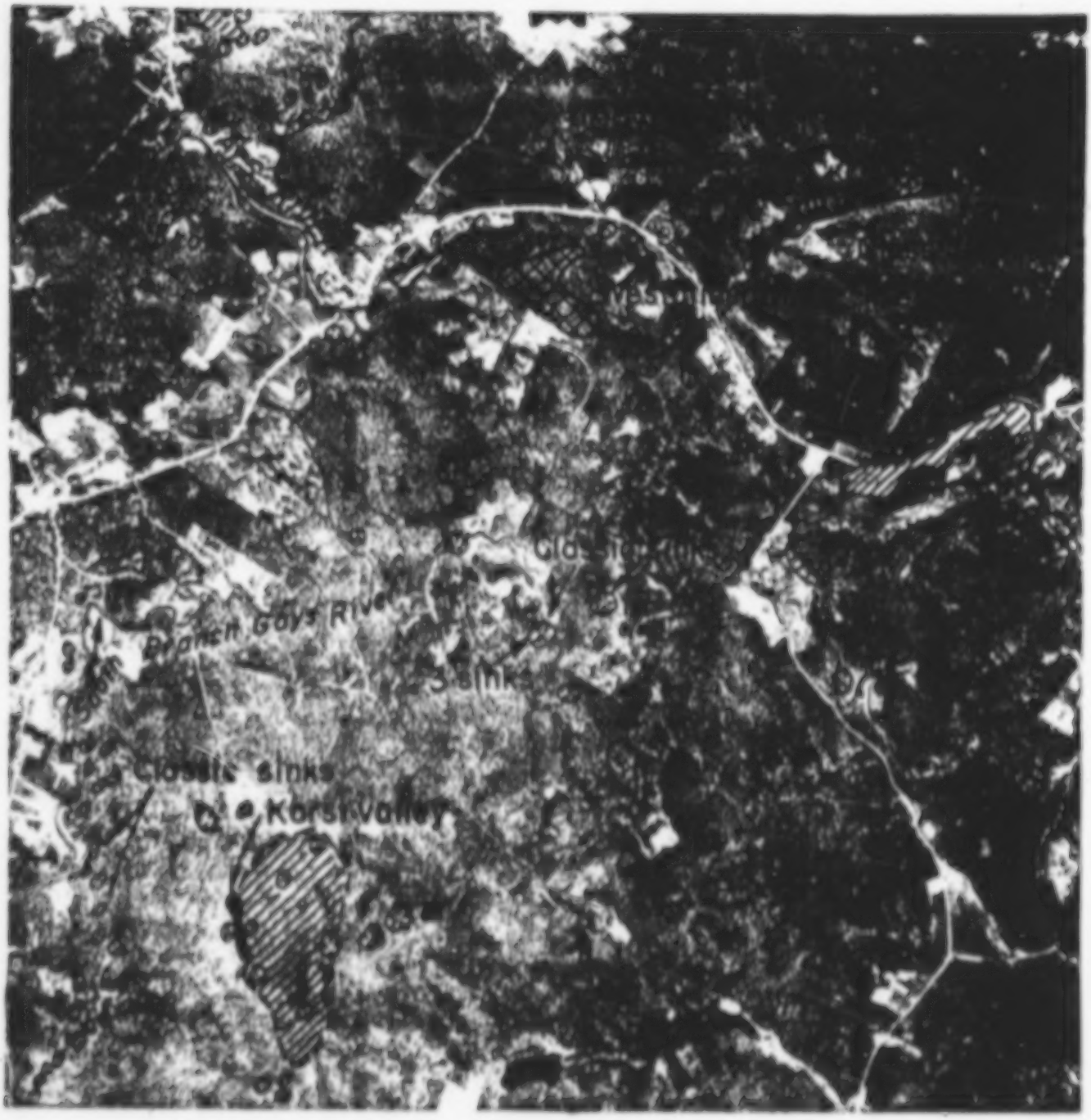
FIGURE 32



LEGEND

- Classic and inferred sinkholes
- Inferred karst valley
- Gravel deposit

1959 PHOTO(B&W)

SINKHOLES INTERPRETED
FROM JUNE 5,1959 PHOTO

0 1 2 km

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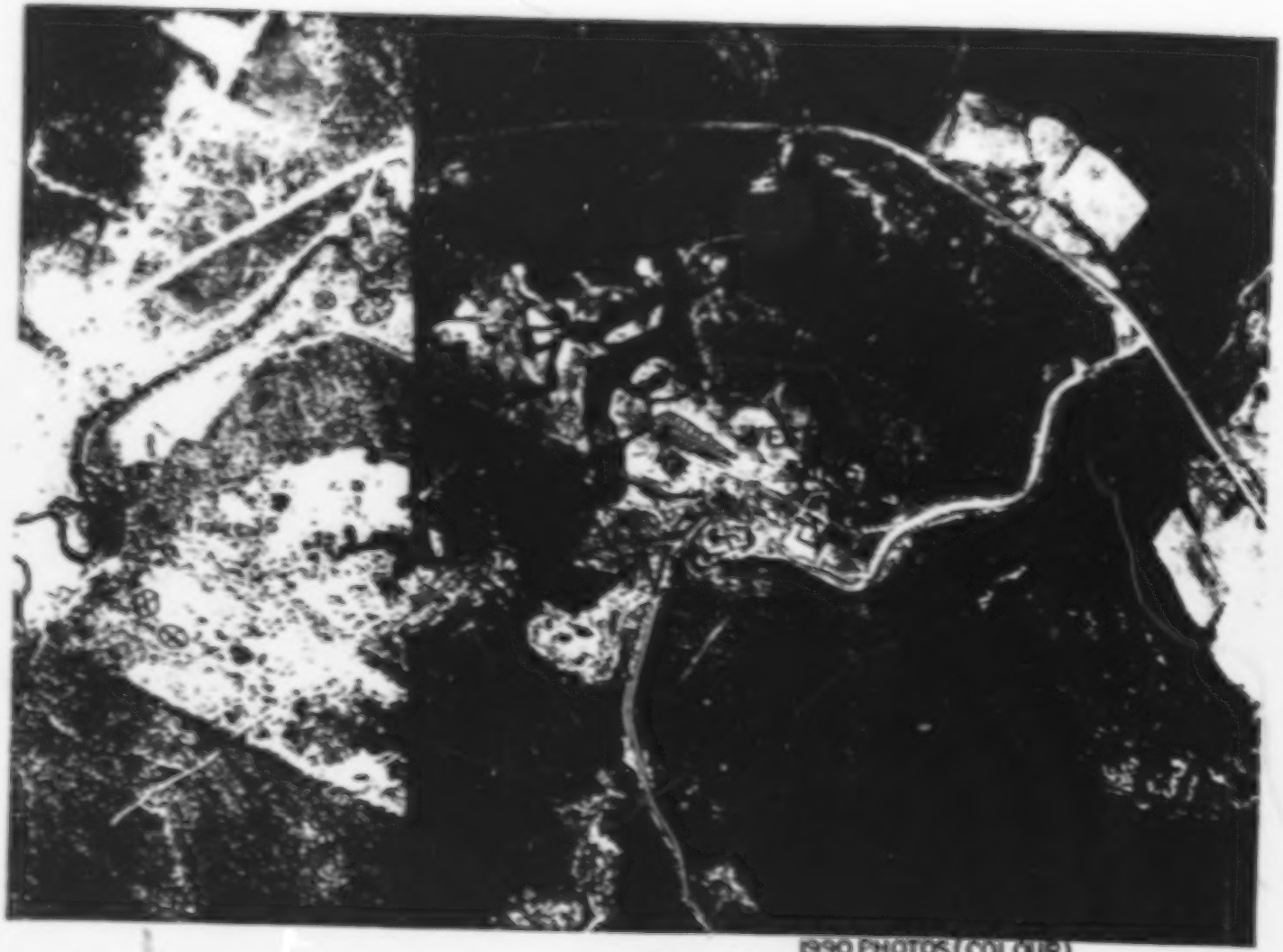
FIGURE 33



Mapped sinkholes various sources

Possible additional sinkholes from airphotos

Plan of underground mine workings

1990 PHOTOS (COLOUR)

MAPPED (OBSERVED) SINKHOLES AND ADDITIONAL POSSIBLE SINKHOLES FROM AIRPHOTO STUDY

0 500 1000m

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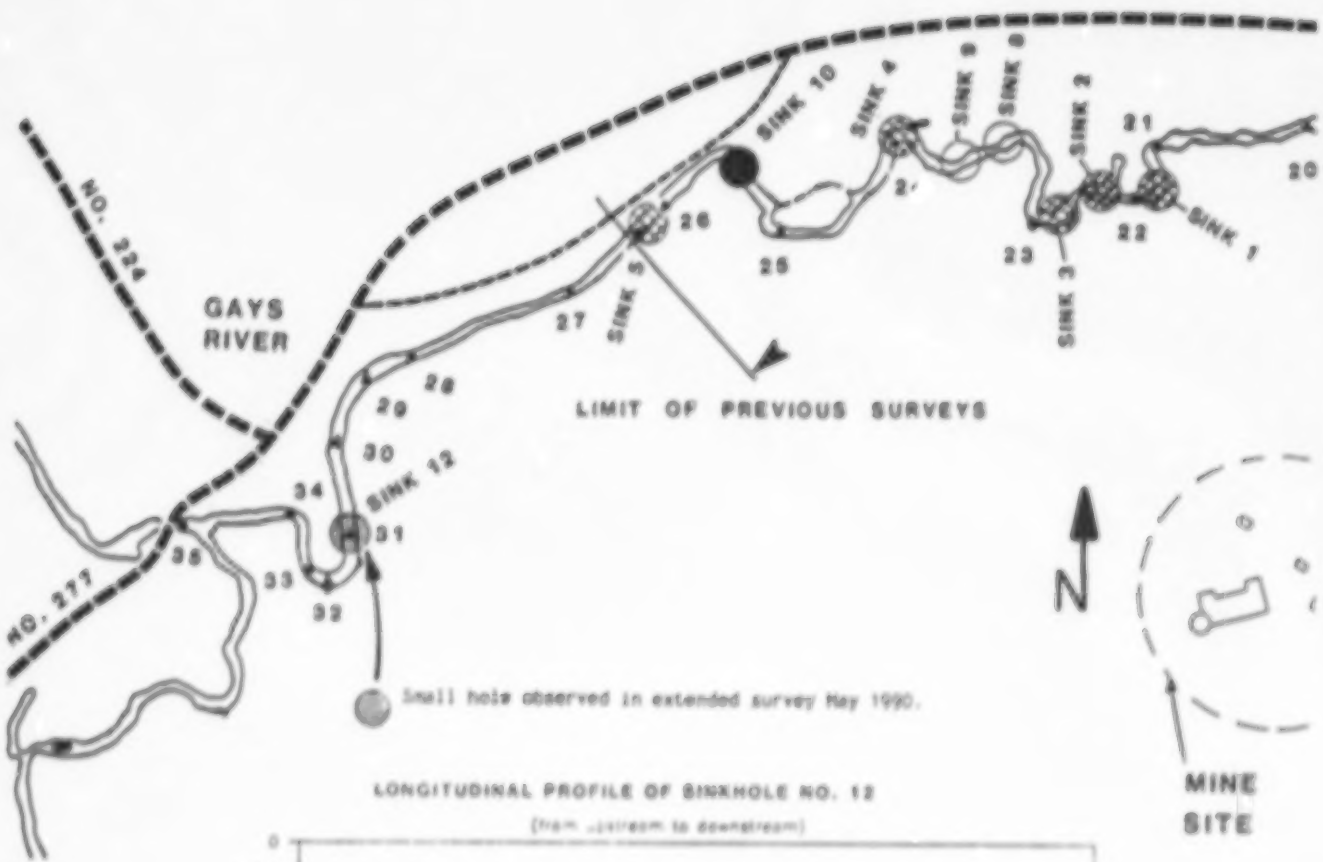
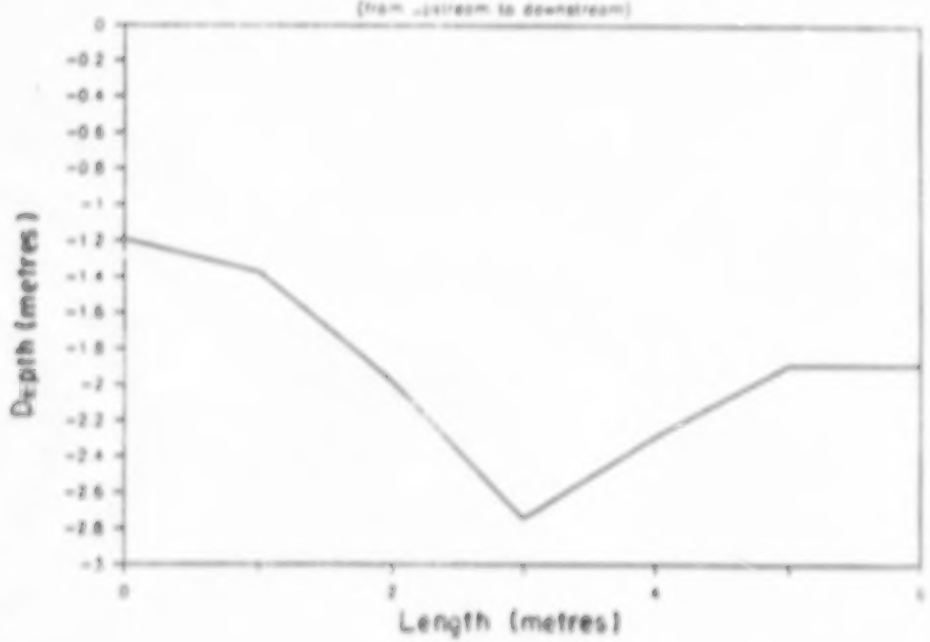
FIGURE 34



LONGITUDINAL PROFILE OF SINKHOLE NO. 12

(from upstream to downstream)



PROFILE OF SINKHOLE No.12 FROM MAY 1990 BATHYMETRIC SURVEY
(from Martec Bathymetric Survey)

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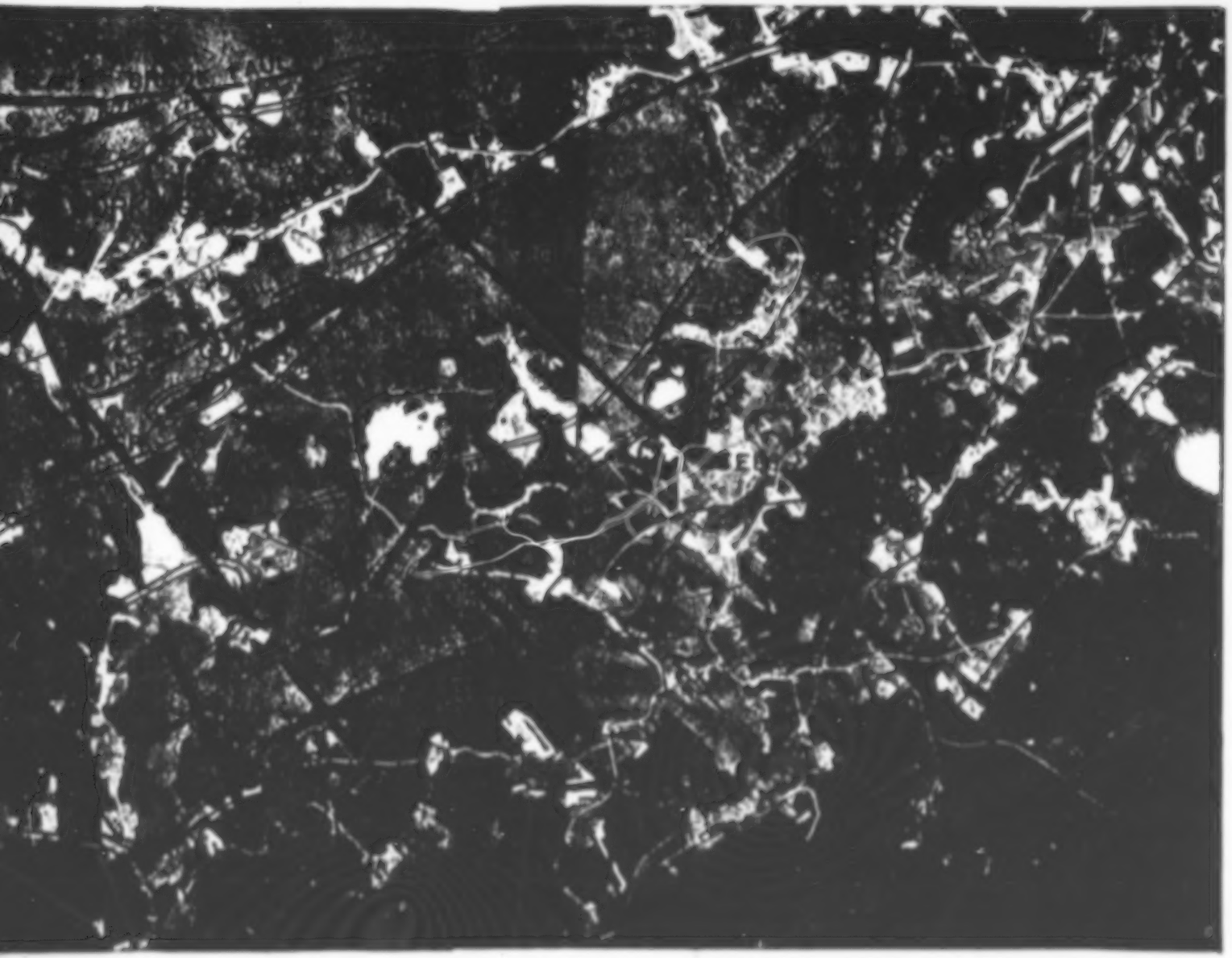
July, 1991

FIGURE 35



LEGEND

- Individual sinkhole or sinkhole cluster (inferred from airphotos)
- Schistosity or bedding trend (inclined or vertical)
- Drumlin (ice-flow direction)
- Linear trends in the relief (surface topography)
- Lithologic / formation contact

1979 PHOTOS (B&W)

0 1 2 3 4 5 km

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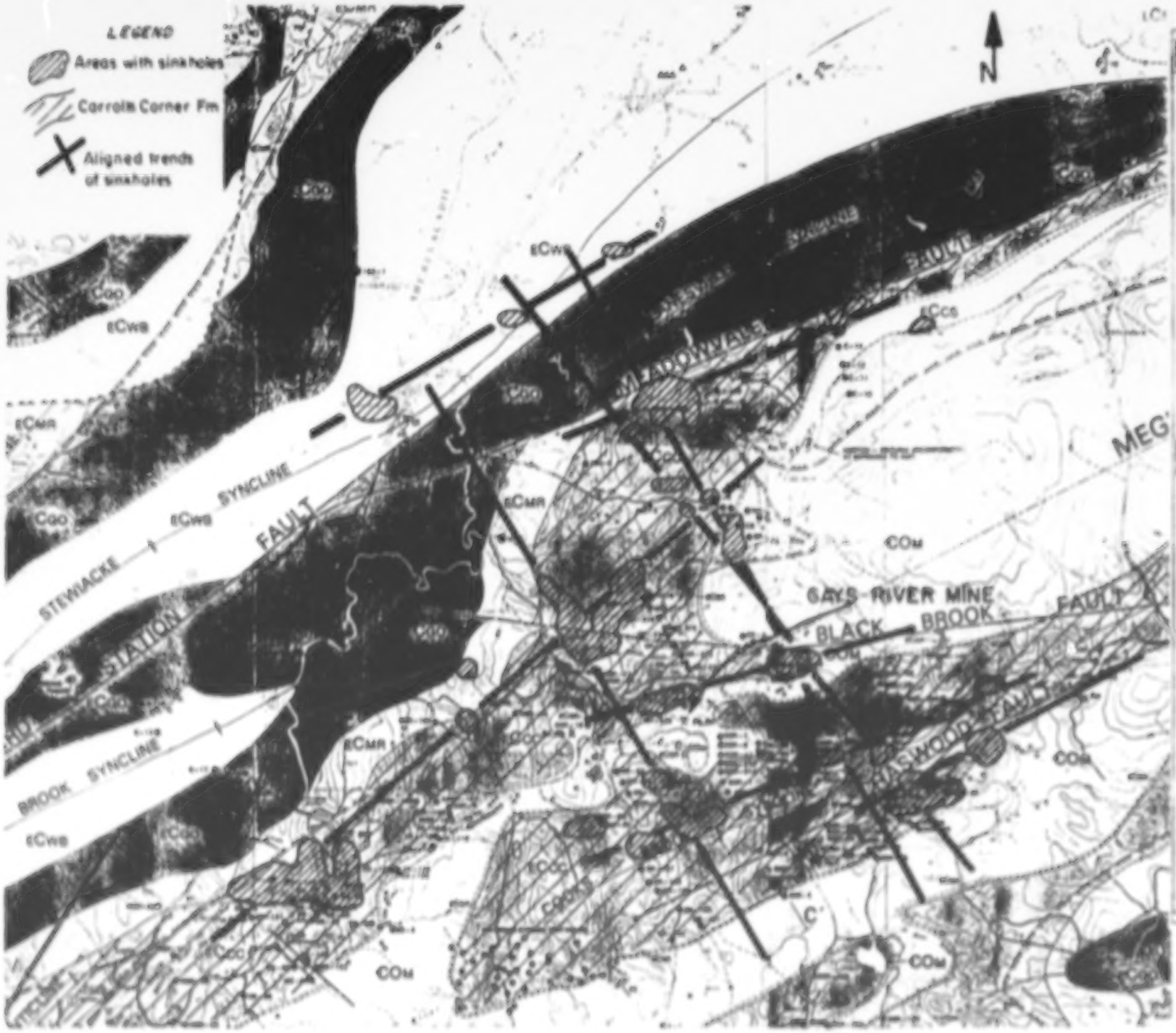
FIGURE 36



REGIONAL BEDROCK GEOLOGY MAP SHOWING AREAS WITH TWO OR MORE SINKHOLES (GILES AND BOEHNER, 1982) NOTE ALIGNMENTS ALONG NW AND NE TRENDS IN THE GAYS RIVER MINE AREA

0 1 2 3 4 5 km

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FIGURE 37